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NEW THEORIES
OF MATTER AND OF FORCE.

NEW THEORIES
OF
MATTER AND OF FORCE

BY
WILLIAM BARLOW



London
SAMPSON LOW, MARSTON, SEARLE, AND RIVINGTON
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—
1885

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PREFACE.

ANY one opening this volume will not be likely to proceed far before the question comes into his mind —What led the author first to entertain conceptions of the fundamental nature of things which are so unusual, which owe so little to generally accepted theories, and are, indeed, in many cases antagonistic to these theories?

To meet any such questioning, and to satisfy the reader that he is not being treated to some mere figment of the author's imagination, but to conclusions drawn, whether rightly or wrongly, from actual facts, the author would say that the general theory, or cluster of interdependent theories of matter and of force submitted in this volume, result from the careful consideration of the more salient phenomena of the different branches of physics, with the aid of a clue obtained by the author when endeavouring some time since to assign to the luminiferous ether known properties of matter which should be adequate to account for its propagation of light.

He first reached a rude theory of the nature of the ether according to which the transmission of wave-motions

depended on the mutual repulsions of similarly electrified particles, and from this, by degrees, he arrived at the conception contained in these pages, of two compressible, elastic, gas-like ethers, adequate, as it will be argued, for the transmission both of light and of electricity.

The evolution of this conception was assisted and materially influenced by the discovery that the existence of two ethers of some such description would account for much more than the author at first hoped, and that facts in all branches of physics could be made to yield evidence as to the precise nature of these two ethers.

The strongest arguments for the acceptance of some such theories as are here submitted are that they account for all kinds of action at a distance, and also afford an explanation of most of the cases of correlation found subsisting among physical phenomena; and further, which is perhaps the most important evidence of all, that they account for many of the definite quantitative laws and relations of physics and of chemistry.

Thus these theories can be shown to account for the law of inverse squares as found in gravitation, the fact that the electrical capacities of similar conductors are as their linear dimensions, the law of refraction known as the "law of sines," the law of reflection, the fact of maximum polarization by reflection taking place when the angle of incidence is such as to give the direction of the reflected ray perpendicular to the direction of the refracted ray,

Joule's law for electric currents that the amount of heat generated in a given time varies directly as the product of the resistance of the wire into the square of the strength of the current, the fact that bodies combine chemically in simple proportions, the fact of the simple relations subsisting between the gaseous volumes of compounds and of their constituents, and finally for several cases of the association of particular crystal forms with particular chemical groupings.

Some conclusions relating to crystallization derived from the following arguments appeared in December, 1883, in "Nature," Nos. 738 and 739, vol. 29, under the heading "Probable Nature of the Internal Symmetry of Crystals." The paper received some approval, but was necessarily too fragmentary for any extended criticism, and it did not contain the fundamental theories at the root of the author's system.

The treatment of so wide a range of subjects is of necessity often cursory, and the author does not for a moment suppose that the particular theories reached are final; all he contends is that the concurrence of the evidence in their favour drawn from such various sources establishes the probabilities that they are at least an advance towards the truth, and that the fundamental suppositions on which they are based are correct.

Most readers will probably consider that in some few places the text is unnecessarily burdened with well-known

rudimentary details ; the reason for the introduction of any apparently superfluous matter of this kind is that the author desires to make his book readable as a whole by those who know a little about one or two of the subjects treated, but nothing about others.

The author intends at a future time to offer further evidence in favour of his theories, based upon the phenomena of crystallization, of meteorology, etc.

MUSWELL HILL,
March, 1885.

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NEW THEORIES OF MATTER AND OF FORCE.

INTRODUCTORY CHAPTER.

THE discovery made by the chemist that all the innumerable forms of matter with their infinite variety of properties have been built up from a very limited number of substances, *the elements*, is of comparatively recent date in the long history of science.

Although at present no further simplification has been attained, there are not wanting indications that these so-called "elements" are not in a strict sense elementary, but are derivatives one of another, or of some unrecognized simpler forms of matter.

Further, some unsuspected and hitherto inexplicable properties of matter, and some obscure relations found subsisting between matter and force, suggest that the discovery of the nature of absolutely elemental matter, if it should ever be made, will be found to involve the discovery of the secret of transmutation of energy.

In the following pages an endeavour is made to go behind the so-called "elements," and to show that these are really compounds of more elementary substances possessed of certain essential properties. And also, which is still more important, to show that *the many* different pro-

perties and manifestations of force which distinguish the various more or less complex substances around us, all spring from, and are the direct and inevitable outcome of, *these few* essential properties of elemental matter ; this latter involving explanations of the correlation subsisting between different physical phenomena, and of the facts which have led to the enunciation of the doctrine of the conservation of energy.

Although, in the course of this treatise, the writer will be led to offer an explanation of the facts upon which the conceptions of the modern system of chemistry are based, and to speak of atoms and of molecules, he will found his arguments upon known properties of matter, and will not attempt to go behind these to follow the speculations of molecular-physicists. Thus, while the property of expanding *in bulk* after it has been compressed, so generally exhibited by matter in all its forms, and known as *elasticity*,* will be regarded as a universal attribute of matter, no attempt will be made to account for it. And, in speaking of *cohesion*, no *attractive force* will be implied ; the supposition very commonly made, that cohesion is the result of attraction between ultimate particles, not being meddled with.

To excuse his reticence on points so fundamental, the author would submit—

First, with regard to elasticity, that he finds all conceptions of motion, at all capable of accounting for this attribute of matter, more difficult and less elementary than the bare conception of elasticity itself ; and further, that he has this difficulty—that all material movement and all kinds of strain are in these pages traced to the elastic expansion of a supposed primary matter ; and to deduce another kind of force from elasticity, and at the same time to refer

* It will be argued that *elasticity of shape* may be produced by the combined action of elasticity of bulk and cohesion.

elasticity to this force, would manifestly be to reason in a circle.

Further, he might urge that as we really do not know what, in the abstract, space is, and have no means of realizing it except relatively, we have no sufficient reason for accepting the dictum of Lucretius that there could be no motion if atoms fill the universe, "for," says he, "the atoms which give way first must have some empty place to move to." It seems possible to demur to such an assertion, because it is based upon the assumption that a given piece of matter must—deducting, of course, all interstices—always occupy precisely the same amount of absolute space ; an assumption of which there is no possible proof.

Some attributes or properties of matter must be regarded as fundamental ; and why not the attribute of elasticity, which is perhaps as manifestly universal as any ?

Secondly,—The author would say with regard to cohesion, that the conception of this as merely a holding force, a force of attachment, and not as in any sense a drawing force, will in the sequel appear adequate, in conjunction with our other hypotheses, to account for all the phenomena of attraction, and indeed for all action which appears to be action at a sensible distance, however small.

The reader's attention is called to the fact that there is an important line of argument in the second chapter of this work which has some application quite apart from the acceptance or rejection of the author's distinctive views as to the constitution of matter. The theory of symmetrical intermixture there offered will explain the spontaneous intermingling of fluids, whether gaseous or liquid, without recourse being had to any unusual hypothesis.*

It should be said, in closing these introductory remarks, that while the arguments of this treatise extend to all matter, including that which is manipulated by life forces,

* See page 38.

whatever these may be, there is no attempt to go beyond the inorganic. Thus no sympathy is here manifested with the tendency to confound forces which, so far as we know at present, are extrinsic to matter, with matter itself, and with forces intrinsic to it ; in other words, to confound life forces, which are not universally present and therefore not intrinsic, and without which the existence of the material universe is perfectly conceivable, with the apparently intrinsic forces, heat, light, electricity, chemical action, crystallization, which are everywhere producible, and seem necessary to the very existence of matter, as we know it.

CHAPTER I.

FUNDAMENTAL HYPOTHESES.

AS a basis for the arguments which are to follow, it is proposed to set forth—

(1) A description of what elemental matter is conceived to be.

(2) A description of a force of compression conceived to have been applied to this elemental matter, as the result of the application of which it became moulded into the forms of inorganic matter with which we are acquainted.

Both these are to be received hypothetically; no further hypothesis in any sense fundamental will be found requisite in the course of this treatise.

The following is the description of elemental matter, which, as will be seen, ascribes to it certain of the recognized properties of matter.

All matter consists of two elementary substances, which when uncombined, and not subjected to extreme pressure, resemble gases in that they are compressible and elastic, and that as they are freed from pressure their tenuity becomes practically unlimited.

They differ from each other in that when, being under the same initial pressure, the same increment of pressure is applied to both, the one has, in all cases, a greater increment of contraction than the other,* and we accordingly

* Their behaviour is thus paralleled by that of gases at high density, which are *not* then obedient to the law of Boyle—that the volume of a given mass varies inversely as the pressure.

designate them *the more readily compressible ether* and *the less readily compressible ether*.

At some low pressure the density* of the more readily compressible ether is less than that of the less readily compressible ether, and thus a certain pressure is conceivable, subjected to which the two ethers have the same densities, and which forms, therefore, a critical point of such a nature that for equal pressures upon the two ethers below it, the less readily compressible ether has the greater density, while for equal pressures above it the more readily compressible ether has the greater density.

These elemental ethers are distinguishable from gases by the far greater fineness of their ultimate particles, if the fact of their elasticity requires us to suppose the existence of such, so that for all practical purposes they are to be regarded as homogeneous.† And they also differ from gases in requiring a far greater force of compression to cause them to approach the greatest possible condensation.

Some cohesion or stickiness subsists among the ether particles at all densities, both between particles of the same kind and particles of diverse kinds of ether; the law which regulates the degree of this cohesion being that the total amount of cohesion in any given mass of the same kind of ether is constant‡ whatever the density. To put this hypothetic law in algebraic form:—If a given mass of ether is in the form of a cube the force necessary to just overcome the cohesion subsisting, say in a plane section taken parallel to one of the faces of the cube, and *simultaneously* to break away particle from particle through-

* For a definition of density, see Note ^o, p. 7.

† This will allow us to regard the uncombined ethers as possessing a readiness of movement, and facility of penetration of small interstices, far greater than those evinced by gases.

‡ This would seem to involve the conception of ultimate particles of fluctuating magnitude, between which the cohesion to be estimated subsists.

out this section, is constant whatever the magnitude of the cube, and therefore the force necessary to overcome the cohesion in a unit of such a surface, and which force we may take as the unit of the force of cohesion, varies as $\frac{1}{l^2}$, if l be the length of a side of the cube.

In the case of cohesion between two different kinds of ether it is supposed that the density of the less dense of the two regulates the law just stated.*

The cohesion, which thus increases with increase of density, modifies the expansive force of the ethers, so that as they are more and more highly condensed they manifest less and less force of elastic expansion on release from pressure, till at a sufficiently high condensation they manifest none.

Further, in the case of extremest condensation the viscosity of the ethers, *i.e.*, the degree of resistance they oppose to the relative motion of their parts, becomes indefinitely great, so that they reach a perfectly solid state.

Finally, the ether particles, like all matter with which we are acquainted, have the property of inertia.

It is supposed that the origin of the two ethers just described, preceded in time the application of any external force affecting them ; and in their primary condition they may be conceived as without motion, or regularity of disposition in space, and uncompressed.

We next come to a description of the hypothetic force conceived to have been applied to the elemental matter, and

* Density is supposed to be determined by the quantity of matter present per unit of space. And to enable a comparison between the densities of the two kinds of ether, we may suppose that equal volumes of the different ethers which possess the same amount of internal cohesion contain the same quantity of matter and have the same density. This will suffice to define density without reference to gravitation or other properties of the more complex forms of matter.

which we shall endeavour to show in the following pages would be competent, partly *directly*, but more largely *indirectly*, by a legacy of reaction which it left behind it, to mould an inert mass of the ethers we have described into the various forms of inorganic matter with which we are acquainted, and to develop their characteristic properties and forces.

This force is conceived to have been simply a force from without, of limited duration, universally applied to compress the primeval ethers, and which gradually diminished their bulk until they had suffered nearly the greatest amount of condensation possible.*

This completes the fundamental hypotheses of this treatise. As a preparatory step to building upon these hypotheses a theory of the structure of the "elements," and a number of other theories, we shall in the next chapter deduce a general law of great importance.

* Nothing can be known or conceived of the spatial extent of the material universe. Of course if any limits be assigned, the condensation of hitherto uncompressed matter just supposed would involve portions of space being left void of matter.

CHAPTER II.

THE LAW OF SYMMETRICAL INTERMIXTURE.

THE law we thus designate, and whose existence we shall now endeavour to prove, may be stated as follows :—

If two elastic fluids capable of intermixture, both of which have some viscosity, *i.e.*, oppose some resistance to the relative motion of their parts, *and which differ from each other in the amount of compression they experience under the same increments of pressure*,* are placed in contact and subjected to a gradually increasing or gradually decreasing pressure, or to a series of such pressures, they will proceed to intermix wherever their boundaries touch, and a mutual uniform distribution of one fluid throughout the other will take place, of such a nature that both fluids, where intermixture occurs, will tend† to become arranged in small equal masses symmetrically situated in space with respect to one another. And, further, the quantity of matter in each of these small masses will be determined by their degree of condensation at the moment of their production.

The proof of the existence of this law which we have to offer is as follows :—

For any particular particle of either fluid to continue to occupy the same situation relatively to surrounding particles while a change of pressure is taking place, it is evident that the pressures on opposite sides of it trans-

* By hypothesis the two ethers thus differ.

† See Note *, page 10.

mitted by these particles must simultaneously change in *the same ratio*, and thus continue in equilibrium about it.

But, unless the two fluids are *both symmetrically disposed* around the particle, this condition of equilibrium will not subsist ; for, by hypothesis, any change of pressure which takes place produces different degrees of compression in the two fluids, and is therefore unequally transmitted by them. And every change of pressure will, therefore, continually produce some change in the situation of the particle, relatively to other particles, *so long as the disposition of these Particles around it is not symmetrical*. As this applies to all the particles of both fluids, especially to those in contact with dissimilar particles, we see, therefore, that change of pressure will tend to subdivide and disperse each fluid throughout the other, and to produce a uniform symmetrical mixture of some kind.

Now, it is evident that the finer the subdivision of the two fluids caused in this way wherever they come in contact, the smaller, on the one hand, the motions of rearrangement producing it, and the larger, on the other hand, the extent of surface at which the fluids come to touch each other, and throughout which there is friction of one upon the other during change of pressure. Therefore, however little viscosity the two fluids may possess, there will in every case be a certain definite fineness of subdivision producible, depending on the nature of the fluids and the changes of pressure to which they are subjected, beyond which *the inequalities of internal pressure* occurring are too feeble in their action to overcome the viscosity, and therefore unable to cause any rearrangement of particles.

This critical degree of subdivision of the symmetrically intermixing fluids will evidently be that produced in each case ; in other words, as above stated, both fluids will tend*

* As for every small mass to have all the other small masses of both fluids symmetrically arranged around it, we should have to

to become arranged in small equal masses symmetrically situated in space with respect to one another; all less symmetrical dispositions of the two fluids than this being always subjected to change by every change of pressure.

It is evident that if different parts of the two fluids experience *similar fluctuations of pressure at different times*, instead of the pressure being always kept uniform throughout the mass, the above law will still hold.

That the quantity of matter in each small mass of either fluid will depend on the degree of expansion subsisting at the time of its ultimate formation is evident. Also that any *increase* of pressure occurring after a quite symmetrical intermixture has been once produced will not cause any further rearrangement.

It is to be observed that when the whole of one fluid has been reduced to small equal masses, and symmetrically distributed among corresponding small masses of the other fluid, there will, unless the two fluids are present in such proportions as to furnish an equal number of small masses of each, be a residuum of one fluid undistributed throughout the other in the symmetrical manner referred to.

As to the *nature* of the symmetrical arrangement produced, we notice that there are but two kinds of disposition of *equal* infinite numbers of two sorts of similar *small* bodies in space which are completely symmetrical, and in which each sort is evenly distributed through space, as shown by the property that when the centres of the bodies nearest to any body of the system are joined the solid thus outlined has equal edges.

They may be exhibited in the following manner :—

suppose the matter intermixed to extend infinitely in all directions, less and less symmetry being obtainable as we approach any boundary, it is evident the intermixture will only *tend* towards the great symmetry referred to, and never completely reach it in any finite case.

Take a number of equal cubes of two different colours, say black and white, and proceed to build them into a continuous mass in such a manner that no cube shall touch any other cube of the same colour except at its edges, or, in other words, so that a section of the mass parallel to either of the three directions of the faces will present the appearance of a chess board, no square being next to a square of the same colour ; then

(1) If, disregarding the distinction of colour, we suppose a number of similar bodies of one sort placed with their centres at the *centres* of all the cubes, and a number of similar bodies of another sort placed with their centres at all the cube *angles*, we have an example of one of these systems of symmetrical arrangement.

(2) If we suppose a number of similar bodies of one sort placed with their centres at the centres of the black cubes, and a number of similar bodies of another sort placed with their centres at the centres of the white cubes, we have an example of the other system.

We submit that the symmetrical arrangement to which the small masses above referred to tend in obedience to the law we have endeavoured to establish will always be that of one or the other of these two systems, in both of which the relative disposition of the bodies of one kind is precisely similar to that of the bodies of the other kind, and the evenness of distribution in space perfect.

We may remark in passing, that in adverting to the supposed nature of the symmetrical disposition of small masses of the two fluids, we appear to be treading upon the border land of a most deeply interesting and hitherto little known province of physical law,—the formation of crystals ; and may say, as we break off the inquiry into the subject of symmetrical intermixture at this point, that when it is taken up again in the chapter on crystallization, proof will be submitted of the existence of symmetrical



THE LAW OF SYMMETRICAL INTERMIXTURE. 13

arrangements of small masses of different kinds of matter of the nature just described.

The very wide application of the law of symmetrical intermixture in accounting for a great number of the phenomena of physics, which is shown in the following pages, will afford experimental evidence of its existence.

CHAPTER III.

THEORY OF MOLECULAR MATTER.—THE ELEMENTS.

THE task which lies before us in this and subsequent chapters, is to endeavour to show that the experimental facts respecting matter and force can be accounted for by the aid of the foregoing hypotheses, that (1) the various properties exhibited by inorganic matter, in all its forms, are such as certain different combinations of the two ethers, the results of symmetrical intermixture produced by the temporary incidence of the hypothetic force of compression, would display ; and that (2) the various processes, and exhibitions of force, which are taking place in nature, including even those which take place at the bidding of life-forces, whatever these may be, are capable of being regarded as so many different incidents of the gradual return, during countless ages, of these various different combinations of the ethers, to the normal tenuous condition after the removal of the hypothetic force of compression.

In the present chapter we shall indicate how the production of a number of ether combinations, which we believe constitute the different simple forms of matter known as the “elements,” is conceived to have been a primary result of the temporary subjection of the hypothetic ethers to the hypothetic force ; and, at the same time, we shall point out the probable salient peculiarities* of the different states of these ether combinations, caused by the inter-

* The identity of these peculiarities with some of the well-known properties of matter is argued in the next chapter.

action of the two kinds of ether composing them on one another.

The application of the hypothetic force of compression, and the reaction which, owing to the elasticity of the ethers, would follow the cessation of this force, would, it is argued, through the operation of the law of symmetrical intermixture, produce some such different effects as the following, in different parts of the general mass of irregularly distributed ethers, according to the proportions of the two ethers present anywhere, and the particular variations of pressure consequently induced.

As the simplest effect we can conceive, if anywhere, as a symmetrical intermixture of the two ethers was completed by the change of pressure, the condensation of both ethers became so great as to give the extremest cohesion of both, there no expansion of either ether would occur on the cessation of the force of compression, and the intermixed mass would present complete stability at a very high density.

Proceeding to other conceivable effects, not so simple. Where the high cohesion accompanying the high density did not thus entirely prevent expansion of either ether on the cessation of the force of compression, the expansion of both would take place simultaneously, though with comparative slowness at first through the restraining influence by hypothesis exerted by the cohesion. But, presently, owing to the different cohesions in the two ethers causing the less dense, *i.e.*, the less readily compressible ether, to expand more vigorously than the other, after some increase of bulk had taken place, the expansion of the small masses of less readily compressible ether of the intermixture would become more violent, while the expansion of the small masses of more readily compressible ether was still inconsiderable.

And when this violent expansion of the small masses of

less readily compressible ether interspersed throughout the mass occurred, if the cohesion of the more readily compressible ether were great enough to prevent its disruption,* an effect would evidently follow analogous to that caused by the liberation of minute quantities of gas within a viscous mass, and *a cellular condition would be produced*, roughly comparable to that of dough, or that of molten lava; the more readily compressible ether being that flattened out into cell walls, the less readily compressible ether that forming the rounded masses of the cell interiors.

Now, for the cells thus formed to enlarge in obedience to the expansion of the ether within them, the superficies of their walls must increase, and for this to occur without any considerable expansion of the highly-condensed ether composing these walls, a continual re-arrangement of the particles must take place, which re-arrangement would be checked by the viscosity of the highly-condensed ether, *and we see that on the facility with which the cell walls extend and the cells enlarge* depends which of two different results is reached at any particular point.

For (1), if anywhere, *the growth* of expansive force within the cells, *occurring as the restraining influence of cohesion diminished, was more rapid than the actual expansion allowed by the extension of the cell walls*; and so the pressure of the ether of the cell-interiors on the cell walls increased as the mass expanded; there it is evident the ether of the walls would acquire increased density, and expansion would be more and more checked, until the cell walls became so condensed as to be incapable of further extension, and expansion ceased altogether. And wherever this was the case, after some, perhaps slight, general expansion, the mass of mixed ethers would assume a condition of

* A glance at the system of cubes of two colours above described shows that each cube is *completely enclosed* by cubes of the other colour.

great stability, small masses of slightly expanded less readily compressible ether being locked within cell walls of more readily compressible ether so condensed as to resist any effort of the enclosed ether to further extend and thin them out.

While, on the other hand (2), if anywhere, *the extension of the cell walls was sufficiently rapid to prevent any increase of pressure within the cells from arising through the growing force of expansion of their contained ethers*, there, it is evident, expansion would go on indefinitely, unless some external restraint prevented.

In this case, however, nearly all the increase of bulk during the earlier part of the expansion would be due to the expansion of the small masses of the less readily compressible ether, the ether of the cell walls continuing in a very highly condensed state, on account of its greater cohesion. And thus, as in the other case, the mass of mixed ethers would present, for a time at least, a cellular structure, the difference being that in the latter case the expansion would be unlimited, unless checked by some external restraint, the cell walls, as the expansion proceeded, becoming extended into very thin films.

The magnitudes in masses of ether thus constituted would, of course, be quite infinitesimal, and we have said that the disposition of the ethers would be symmetrical; but as a rough illustration we may liken the structure produced to a mass of soapsuds; and this illustration has the advantage that it constitutes a practical proof of the possibility of the force of cohesion holding together a mass of matter arranged in the way last supposed.

We may add that the expansion would be far less violent than that of unmixed ethers; in other words, *that a far less force of compression would be requisite to continue a mass of ethers thus intermixed than a mass of unmixed ether of either kind at a degree of condensation*

*near the greatest possible.** For by hypothesis the continuing high density of the ether of the cell walls would hinder the re-arrangement of their particles necessary for the enlargement of the cells. Indeed the very violence of the expansion would hinder cell enlargement, although it would not prevent it as in the former case.

Before suggesting other possible effects it will be convenient to give some name to the units in the symmetrically-arranged mixtures above described, which we suppose constitute the simplest forms of molecular matter, and we will therefore call each of the small masses of ether individualized by the law of symmetrical intermixture *primary atoms*; and this designation will apply to small masses of either ether. Further, we will call each of the minute cells, consisting of the small mass of less readily compressible ether of a single cell interior and so much of the more readily compressible ether of the enclosing cell wall as proportionately pertains to a single cell, *a simple primary molecule*.

The reason for applying these well-known names in this manner is the belief that corresponding units of symmetrical intermixtures of the different elements produced while they are in a gaseous state form the atoms and molecules of modern chemistry. The ground for this belief is stated in the sequel (see p. 342).

To continue our investigation. As another conceivable effect:—If anywhere a mass of simple primary molecules, built up, as above described, by a process of symmetrical intermixture, had one kind of primary atoms very greatly expanded, the other extremely condensed, and while in this state, *during the continuance of the variation of pressure*, came in contact with a mass of the less readily compressible ether, there it is evident a second symmetrical intermixture would commence, small masses of what we

* See p. 8.

have supposed to be the simplest form of molecular matter taking the place occupied in the former intermixture by one kind of primary atoms.*

The units of mass, or molecules, in such a combination, we will call *complex primary molecules*. The quantity of ether contained in each of the primary atoms, or small masses, into which the unimolecular ether was broken up by its intermixture with the tenuous molecular matter, would evidently depend on the conditions under which they were produced.

Finally, a yet more complex effect may be conceived. If anywhere a mass of such molecules as last described had one kind of atoms only very greatly expanded, and while in this state and during the continuation of the variation of pressure, came in contact with a mass of the less readily compressible ether, or with some other mass of primary molecules of different composition but in a similar state,† there it is evident symmetrical intermixture would again commence, and a mass of still more complex molecules would be produced.

The evidence that the elements are certain ether compounds, more or less related in constitution to one another, of the nature we have thus indicated, consists in the possibility, we shall in these pages attempt to establish, of framing plausible theories of the various principal phenomena of physics based on such a view of the constitution of these simple bodies. Perhaps the most striking parts of this evidence appears in connection with the phenomena of chemical combination and crystallization, the very

* We suppose the films separating the highly expanded atoms in the mass of primary molecules to be successively penetrated by the newly separated atoms of less readily compressible ether without permanent rupture, much as the film of an ordinary soap-bubble is sometimes penetrated by other bodies without being destroyed.

† A necessary condition is that the two masses of molecules change bulk at different rates under similar changes of pressure.

*near the greatest possible.** For by hypothesis the continuing high density of the ether of the cell walls would hinder the re-arrangement of their particles necessary for the enlargement of the cells. Indeed the very violence of the expansion would hinder cell enlargement, although it would not prevent it as in the former case.

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remarkable quantitative and other laws of simple proportion of quantity and of form found to rule these phenomena being hereafter argued to be immediately referrible to just such modes of combination of gaseous elements as those above conceived of the unimolecular ethers. The characteristic properties of each element are supposed to be traceable to the particular proportions of the two ethers entering into its composition, and to their structural disposition.

The different states of the ether compounds which have been suggested above we shall, in the next chapter, endeavour to identify with the different states of molecular matter.

The magnitudes of primary atoms and molecules must be supposed altogether infinitesimal, for the thickness of the film of a soap bubble, when most attenuated, has been calculated to be less than $\frac{1}{156000}$ of an inch, and the thinnest film would be composed of more than one, probably of very many layers of molecules. It will appear from subsequent arguments to be a physical impossibility to make a primary molecule visible by any kind of optical arrangement.

As already intimated, the gradual recovery of the two ethers from the effects of the hypothetic pressure is supposed to be still going on, and to be the source of all the various merely material phenomena around us; but while we shall hereafter argue that chemical combination, and other kinds of molecular change, and changes of state are traceable to this source, we regard the manufacture of primary molecules from ethers, in some such manner as that just indicated, as having taken place, once for all, at the time of the imposition, or immediately after the cessation of the hypothetic force of compression.

According to the views above propounded, *molecular matter is destructible, i.e., convertible into unimolecular ethers*. For the failure of its cell wall must, it is evident,

involve the escape of the ether confined in the cell interior of an expanded primary molecule and the consequent destruction of the molecule, much as the failure of the film of india-rubber of a child's coloured ball involves the escape of the contained gas and the destruction of the ball. As we proceed we shall make the theories of this treatise continually dependent on the supposition that a wholesale destruction of primary molecules, and consequent liberation of unimolecular ethers, is taking place.

In reply to the evident objection to this that no diminution in quantity of molecular matter is discernible, it is submitted that this may be due to the very great extent to which the ethers are compressed when in the molecular state, and to the infinitesimal size of the atoms, so that an enormous amount of molecule destruction takes place without any perceptible diminution of bulk of the molecular matter which is undergoing waste.

And as experimental evidence of the adequacy of such an explanation we may instance the case of odorous bodies. For these bodies are moment by moment giving off innumerable particles, and yet in many cases the amount of waste thus occurring during the lapse of months, inconceivably great as it must be if estimated by the number of particles, is so insignificant as to elude observation, unless the most delicate instruments are used to ascertain it. Further, the expansion to gas of these innumerable particles taking place at the surfaces of such bodies, though a change of so violent a nature that when occurring on a large scale it amounts to explosion, produces no perceptible disturbance whatever.

Surely if a wholesale waste of particles which have sufficient structure to produce a characteristic effect on the organ of smell thus almost eludes observation, it cannot be pronounced intrinsically absurd to suppose that a wholesale waste of primary molecules, in undergoing

which they lose all structure capable of appealing to any of our senses, may take place without the waste being indicated by any of the tests we are able to employ.

It is probable, moreover, that we are not absolutely without evidence of such a waste. For it is found that heating an exhausted tube continuously, or the repeated passage through it of electric currents, improves the vacuum; and as evidence is brought forward in the sequel that, according to the theories of matter here offered, heat commonly produces atom explosion, *i.e.*, molecule destruction (p. 301), and that so also do electric currents, it is conceivable that the improvement of the vacuum arises from the actual resolution of the molecules of the highly-rarified gas into unimolecular ethers. It is proper to remark, however, that the effect has commonly been attributed to the occlusion of the residual gases by the electrodes.

CHAPTER IV.

THEORY OF THE DIFFERENT STATES OF MATTER.

IT is proposed in the present chapter to point out certain conceivable states of such ether compounds as those whose production we have just traced, which may be supposed to be the various different states of molecular matter familiar to us, and also to indicate the probable nature of the different changes from one state to another.

As a preliminary step, however, a short general reference should be made to the means which, according to our hypotheses, subsist for the production of either change of bulk or change of state of ether compounds; the detailed consideration of the causes of such changes will be found in the sections of this work devoted to the subjects of heat, of chemical change, and of crystallization.

And first as to the *contraction* of portions of matter of any kind whatever, it should be stated that, avoiding any hypothesis of attraction, we shall in all cases suggest that contraction of matter is due to pressure supplied by the expansion of other matter, a suggestion which may remind us of the modern dictum, that no work can be done without a commensurate expenditure of energy.

Next as to what means of expansion are conceivable of the ethers of primary atoms, when their condensation has, as in some of the cases above conceived, become so great as to give the extremest cohesion:—It is noticeable in the first place that the conditions *at the outer boundary* of a mass of highly condensed ethers may not be productive of

the same stability as prevails in the interior of the mass, and changes occurring at the outer boundary may gradually extend into the interior.*

Thus if we suppose a mass, which is composed of molecules so highly condensed that the force of cohesion has entirely overcome the tendency to expand, to be surrounded by highly tenuous unmolecular ether, the condition of a particle at a point situated upon its surface will be this: If the particle, as a result of its own elasticity, or the elasticity of surrounding particles, makes any movement normal to and away from the surface, there is, according to our theories, no adequate recuperative force to bring it back again, for there are no highly-condensed molecules present outside it, which by their expansion can create for it a force of contraction. It follows that the outermost particles of the mass will expand, and although, by the molecular expansion and destruction thus arising, expansive force will be liberated, by which particles that lie beneath may for the moment continue condensed, the expansion of the outer particles will presently be followed by the expansion of the particles next beneath them; the expansion of these by the expansion of the particles of the next stratum, and so on continuously; so that, *if time enough be granted*, we must anticipate the complete expansion of all the particles composing the given mass.

And in the next place, as another means of expansion of such highly-condensed ethers, the bursting of molecules, allowing the explosion of their contained atoms, to which allusion has been made, and other changes occurring in molecular matter, must be supposed to produce displacements of the ethers and local differences of pressure, and these, through the great elasticity of the ethers and the inertia of their particles, *to result in wave motions running*

* On this see as to Conduction of Heat, p. 316.



*hither and thither in all directions through both unmo-
lecular and molecular ethers.* Now the vibrations to and fro
of the ether particles in waves thus produced would every-
where cause local fluctuations of density in the elastic
ethers, whether molecular or unmoolecular, diminution of
density occurring wherever ether expansion takes place,
increase of density wherever there is ether condensation.*

Therefore we have deduced from our fundamental hypo-
theses the existence throughout all matter of an agency
productive of the occasional lowering of ether density, and
consequently of cohesion. And if anywhere the diminution
of cohesion caused by this means is too considerable for the
ether condensation which follows ether expansion to neu-
tralize, we shall there have a permanent expansion of a
portion of the mass.†

Let us now see how far we can recognize what are
known as the different states of matter in certain different
conceivable states of our ether compounds.

* Upon the principles of this treatise we have therefore to dis-
criminate between the mean general pressure within a gas or a liquid
and the fluctuating local pressures which are determined by the
passage of wave-vibrations. To take a simple example : suppose we
have an open vessel containing atmospheric air at the normal atmo-
spheric density. We are accustomed to regard the whole of such a
bulk of air as subject to a constant pressure, the weight of the
atmosphere, but if we accept the conclusions of this treatise it is
evident that, since we must regard it as traversed by such waves of
sound as may happen from time to time to be passing, if we fix
our attention upon some particular particle of the air it is not
strictly correct to say that this particle is subject to a constant
pressure, and is therefore at a constant density ; for the sound-
vibrations in which it participates will produce fluctuations of
pressure, the values of which must be distinguished from the value
of the mean general pressure which is unaffected by them.

† Very symmetrical waves of ether, some of which are manifested
by the light, others by the heat they produce, it will be contended
in the sequel are active agents in causing atom-expansion and atom-
explosion in the interior of masses of matter.

It is commonly stated that there are three distinct states of matter, namely, the solid state, the liquid state, and the state of gas or vapour; and these broad distinctions generally suffice for all practical purposes. If, however, our fundamental hypotheses are to be admitted, we must add a fourth to these three states, namely, *the ethereal state*.

In addition to this, the course of subsequent argument will, on many grounds, be found to justify the splitting up of one of the three recognized states into two, distinguishing a *cellular solid state* from a *non-cellular solid state*.

We then have five states of matter broadly distinguishable from each other, viz. :—

1. The non-cellular solid state.
2. The cellular solid state.
3. The liquid state.
4. The gaseous state.
5. The ethereal state.

Of these five states, the first four we suppose are molecular, in the sense attached to this word in this treatise, and the fifth unimolecular; the broad difference between a molecular and an unimolecular state of matter being, according to the views which have been submitted, that molecular matter is a symmetrical intermixture of the two ethers in which either there is no expansive force because of the great density of all the ethers present, or the force of expansion of one ether compresses the other into highly-condensed septa or films whose cohesion restrains this force. Unimolecular matter, on the other hand, is either unmixed ether or an intermixture in which no portions of matter are continuing permanently condensed.

Taking the different states of matter in the order just given, we suppose :—

1. That the non-cellular solid state is the state presented by any mass of intermixed ethers composed of any number of different sorts of primary atoms which have reached the

condition of great stability referred to in the last chapter, in which the atoms of both kinds of ether are so condensed that they manifest no expansive force, except in the fitful way next stated.

Throughout every mass of matter in this state, and indeed *throughout all masses of molecular matter, in whatever state*, local temporary fallings off in density and cohesion, occasioned as above explained, or otherwise, are, we suppose, *continually here and there producing the expansion of small portions of molecular matter to the unimolecular or ethereal state.*

If, as we have said, the expansion of molecular matter is always either prevented or restrained by the cohesion of its denser portions, it is evident the expansive force of ethers let loose in this way within a molecular mass will, as the particles of the mass become rearranged by passing waves, *cause these ethers to percolate through the molecular matter to find a vent*; the facility with which they accomplish this being greater as *their degree of continuity* is greater, and as the breaks made in this continuity caused by any disturbing motions in the mass are less. Every mass of molecular matter will in this way have complete *porosity* for the passage through it of unimolecular ethers.

Again, the degree of tenuity attained by unimolecular ethers which are thus percolating through molecular masses will evidently be limited by the facility with which they pass away; and we suppose that owing to their passage being hindered by the action of one unimolecular ether on the other (see p. 17), their density, although much less than when they were in the molecular condition, is to some extent proportionate to the density of the atoms from which they are evolved. By hypothesis any keeping up of density involves a keeping down of expansive force.

For the non-cellular solid state to continue unchanged the quantity of unimolecular ethers produced by molecule

destruction within a mass in this state as just supposed must, it is evident, bear a quite infinitesimal proportion to the quantity of condensed ethers composing the molecular matter.

Unlike the cellular states of molecular matter that have been described, in which the cohesion of the ether of some atoms prevents or restrains the expansion of other atoms, this highly condensed state is evidently one in which no great internal strain exists.

It will appear probable from subsequent considerations that it is perfectly exemplified only by some few of the metals.

2. We suppose that the cellular solid state is the state presented by a mass composed of any number of different sorts of primary atoms in which one or more kinds of atoms are not so condensed as to prevent their expansion, and the expansive force of these atoms has compressed some or all the other kinds of atoms into septa or cell walls of such a density that their cohesion altogether prevents their expansion and makes them able to bear without spreading or breaking the pressure of the partly expanded atoms which they enclose. We referred to this state in the last chapter (see the first of the two cellular states described, p. 16).

The application to all matter in this state of our general supposition that unimolecular ethers are being liberated throughout all molecular matter, and percolating through it, in this way bringing about its complete porosity for unimolecular ethers, must not be overlooked. As in the case of the other solid state it is evident that, for the state to continue unchanged, the quantity of these ethers evolved must be very limited indeed.

We shall argue as we proceed that most solid bodies indicate by their properties that they furnish examples of this state.

3. As to the liquid state.

It is well known that this state, in the case of some substances, and, indeed, in the case of all more or less, passes so insensibly into the solid state that no line of demarcation can be fixed. Thus before it reaches fluidity iron loses its hardness, and becomes soft, so that pieces may be welded together or moulded into various forms, and some substances, which behave entirely as fluids if sufficient time be given them, have the appearance and properties of solids, on account of their great viscosity, *e.g.*, cold tar and asphalte. And in this way properties which appear at first sight to pertain exclusively to liquids are found, to a limited extent, to belong also to solids; while some properties of solids are found to characterize all liquids.

We suppose the liquid state to be the state of a mass of different kinds of primary atoms, *whose general expansion is prevented by cohesion* in one or the other of the two ways we have just described, when suggesting the nature of the two solid states, *but in which the quantity of unmoolecular ethers liberated, as above supposed, is too great to allow of different parts of the mass rigidly retaining the same relative situation as they do in the solid state*—a state, therefore, in which the mass may be regarded as consisting of a number of small masses of molecular matter in one of the solid states already described, whose *continuous* contact with one another is prevented by the frequent liberation from their surfaces and passage between them of unmoolecular ethers which as they are liberated pass away.

We suppose

4. That the gaseous state is the state presented by a mass of intermixed primary atoms of different kinds in which the considerable expansion of some of the atoms while the rest remain very condensed has produced a cellular condition of the mass in the manner described in

the last chapter (p. 17), *the pressure exerted by the ether of the cell interiors, and consequently the density of the cell walls and their viscosity diminishing as the expansion proceeds*, so that the cells continually enlarge, and the mass as a whole expands, unless prevented by some external pressure. The fluidity of the gaseous, like the fluidity of the liquid state, we attribute to the continual liberation of unimolecular ethers throughout the mass, these ethers percolating through the molecular matter as above suggested.

All gases, we know, are found to have some viscosity, *i.e.*, they oppose a resistance to the *relative* motion of their parts.

5. The ethereal or unimolecular state was defined above. We suppose that matter in this state is never met with by us in any considerable quantity separate from molecular matter, and that what there is of it around us is distributed among small masses of molecular matter. Some of the phenomena of light, of heat, of electricity, of magnetism, and of chemical change will be argued to be due to its presence and its movements.

Next, as to the probable nature of the different changes from one to another of the above states.

Transition from the non-cellular solid to the liquid state we suppose to be due to an increase in the quantity of unimolecular ethers being liberated in small quantities within bodies in the former state—the viscosity, or adhesion of the small masses of the bodies to one another becoming less and less as this increase takes place:—Heat will, in the sequel, be argued to be a principal cause of increase in quantity of the unimolecular ether being liberated within a body.

The liquefaction of bodies which are in the cellular-solid state we suppose to be a very similar change, but that some complication arises from the effect of the increased

liberation of unimolecular ethers on the conditions of internal strain and cellular structure which we have supposed are present in this solid state. The fact that many solids, which we shall hereafter see reason to believe are in the cellular-solid state, particularly crystals, diminish in bulk on liquefaction, leads us to suppose that the effect referred to is the production by local *temporary* accessions of pressure, resulting from the increased ether liberation, of sufficient condensation of the slightly-expanded ether of some, at least, of the cells to make this ether lose its expansive force, so that it continues condensed, and does not press upon the other ether enclosing it. For if, as suggested, the liberated ethers rapidly escape from the interstices of the molecular matter of the mass, such a state of things would evidently cause a diminution of bulk.

Before we refer to the converse of this last change, and the other changes of state which remain to be treated, an important conclusion as to local fluctuations of pressure, and consequently of density and cohesion, should be stated.

We have argued the existence of waves which traverse all kinds of matter, and produce local fluctuations of density, and consequently of cohesion. And we have concluded that, if anywhere the diminution of cohesion caused by this means is too considerable for the ether condensation which follows ether expansion to neutralize, we shall there have a permanent expansion of a portion of the mass.*

If, therefore, here and there throughout a mass which is in one of the highly-condensed states, small portions are permanently expanding through the action of passing waves, it will be at points where the local cohesion, when at the ebb of a wave it approaches a minimum, falls below a *critical value*, at which it ceases to be high enough to prevent the existence of expansive force in the ethers of

* See page 25.

the mass, no permanent expansion taking place where the *minimum* cohesion continues above this critical value.*

In harmony with this, we suppose, *in reference to the transition from the liquid to the cellular-solid state*, that the very extreme condensation of some atoms arising from the expansion of others, which we have supposed to be the characteristic feature of the latter state ; in other words, the cellular condition of this state, is produced *with more or less suddenness* as the conditions of the crystallizing liquid change in such a way as to lower the minima values of the cohesion of the atoms whose expansion produces the cellular condition *past a certain critical value*, depending on the substance employed.† The facts that the change is sudden in many instances, and that it is commonly accompanied by a sudden increase of bulk, are, it is suggested, to be accounted for in this way.

This theory explains the fact that some liquids, when nearly at the point of sudden transition to the solid state—*e.g.*, water near the freezing point—are caused to solidify by lowering the external pressure upon them while other conditions remain unchanged.‡ For it is evident that a diminution of the external pressure upon a liquid will lower all the local pressures within it which are fluctuating between maxima and minima at the bidding of passing waves, and will thus make the minima values of pressure and of cohesion lower than before ; and if, therefore, the minima values of cohesion of the atoms whose expansion produces the cellular-solid state are at the outset just above the critical value above referred to, the diminution of external

* The amount of change produced will thus, it is evident, largely depend on the *amplitude* of the waves.

† An explanation of the probable cause of the lowering of these minima is given in the sequel, p. 302.

‡ As a converse phenomenon.—Moresson succeeded in lowering the freezing point of water to -18°C. , by the application of a pressure of 13,000 atmospheres.

pressure will, if considerable enough, carry them past this critical value and produce a change of state.

In cases where the passage from the liquid to the cellular-solid state is marked by diminution of bulk, *e.g.*, in those of paraffin and spermaceti (which we suppose furnish examples of the latter state), we may suppose that slight expansion of some atoms is overbalanced by a shrinkage of bulk, due partly to the drawing closer together of the atoms generally, as the quantity of unimolecular ethers liberated within the mass diminishes, partly to the compression of the atoms not expanding. And such a theory would explain the fact that bodies which display this property of contracting on congelation, have their melting points raised by pressure, *e.g.*, spermaceti melts at between 50° and 60° , under a pressure of 156 atmospheres, being 3° higher than its normal point of solution. For we should expect increase of the pressure upon a body to diminish the quantity of unimolecular ethers being liberated within it, and since, according to our theories, it is *increase* of the quantity liberated which causes liquefaction, increase of pressure would in diminishing the quantity of ethers liberated, defer change of state, or, in other words, raise the melting point in the scale of temperature.

As to the transition from the liquid to the gaseous state, we suppose that the cohesion at all points of a mass in the former state being, as above explained, kept fluctuating in value by passing waves, the change referred to is brought about by the lowering of the minima values* of the fluctuating cohesion of those atoms whose expansion produces

* We may call attention here to what it is suggested is a familiar example of the existence of points of minimum cohesion in a liquid.

If a glass of soda water or other aerated water is observed as the effervescence is subsiding, it is seen that the minute bubbles of gas passing out from the liquid are moving in regular files at equal distances with almost soldier-like precision.

The explanation suggested is that where a bubble is formed, the

of the effects of change of state, may be adequately explained according to the theories which have been offered.

Take a glass globe of given capacity, provided with a stop-cock, a pressure-gauge, and a thermometer. Introduce into this globe a small quantity of water, and then, closing the stop-cock, expose it to the temperature of boiling water. If sufficient water have been provided, it is seen that the given temperature is adequate to vaporize a certain quantity of water, and no more; so that any excess beyond this continues as a liquid at the bottom of the globe.*

Next, without allowing any of the contents of the globe to escape, and still preserving the same given temperature, introduce through the stop-cock a small quantity of liquid alcohol; it immediately begins to vaporize, and continues to do so until, as in the case of the water, a point is reached at which all the remaining alcohol continues liquid. Further, on investigation, the remarkable fact is revealed that the globe holds almost as much vapour of alcohol as though no vapour of water were present.

Finally, retaining, as before, all the previous contents and preserving the same temperature, in a similar manner, introduce a third liquid—ether. Again an expansion takes place, a certain quantity of the ether gradually evaporates, till with this also a limit is reached beyond which all the residue continues liquid; and, as was the case with the alcohol-vapour so now with the ether-vapour, the capacity of the globe for ether-vapour is found to have been almost as great as though no other vapour had been present.

The general mean pressure exerted by the combination

* This fact is an instance of the law first formulated by Dalton, that, in a space destitute of air, the vaporization of a liquid goes on only until the vapour has attained a determinate pressure dependent on the temperature, so that, in every space void of air, which is saturated with vapour, determinate vapour-pressure corresponds to determinate temperature (see p. 305).

of vapours upon the sides of the vessel is found to approximate to the sum of the pressures which the three vapours would severally exercise, under the given conditions, if present alone.

The explanation of these phenomena appears to be as follows:—

The fact already explained that the boiling point of a liquid is lowered in the scale of temperature by a fall of external pressure, raised by a rise of external pressure, will evidently account for the successive forcing up of the boiling points of the three liquids past the given constant temperature by the pressure afforded by their confined vapours.

The remarkable facts that the presence of the aqueous vapour does not appreciably diminish the capacity of the vessel for the alcohol-vapour, and that the presence of both the steam and the alcohol-vapour does not appreciably diminish its capacity for the ether-vapour, we should interpret as showing that a general or mean pressure, exerted by a less volatile gas or vapour, does not appreciably affect *the position of the minima* of the local density and cohesion of the atoms of a more volatile gas with which the less volatile gas is mixed.

The reason of this, we surmise, is that the existence of different rates of expansion and contraction of different kinds of atoms produces *dissonance of pulsation*, so to speak, when these atoms participate in wave motions, and prevents *continuous* communication of pressure from one kind of atom to another; and that this allows an occasional lapse of the density and cohesion of the atoms of one kind to minima values little or no higher than would be presented if the pressure caused by the presence of atoms of other kinds were removed altogether. The conception is, however, somewhat difficult.

It has been stated as a fundamental hypothesis respect-

ing the two ethers that, under a change of external pressure, the one will expand or contract, as the case may be, more than the other. It is, however, a matter of experience that gases, which we have argued are various intermixtures of the two ethers, have a sensibly constant, and therefore similar, rate of expansion through a wide range of changing pressure. This fact is expressed by what is known as the law of Boyle or Marriotte :—That, provided the temperature remains the same, the volume which a gas occupies is inversely proportional to the pressure subsisting upon it ; or, in other words, its density is proportional to its pressure.

It is evident that, if our conclusions be correct, such a law as this can be but approximately true, and this only between certain limits of density. It would not prove true for a state of very high condensation. And on the other hand, its application to a state of unlimited tenuity would imply the possibility of absolutely unlimited expansion. It is found experimentally to be but an approximate law, Regnault having shown that air and all gases, except hydrogen, have co-efficients of dilatation which increase to some extent with their density.

The accuracy of Boyle's law increases, however, under conditions of increasing tenuity, a fact which is embodied in a second law of Regnault, that the co-efficients of dilatation of the different gases approach more nearly to equality as their pressures become feeble.

The important phenomena of the spontaneous mixing of gases and the diffusion of liquids may evidently be attributed to the action of the law of symmetrical intermixture, the changes of pressure requisite to bring the law into operation being those caused by passing waves, as above explained.*

* The intermixture of gases is referred to again, p. 339.

CHAPTER V.

THEORIES OF GRAVITATION AND CAPILLARY ACTION.

AMONG the fundamental hypotheses of this treatise, no hypothesis of action at a distance is laid down. The reason is, that in all those cases where a body acts on another body without contact with it, and without the intervention of any apparent material connection, we shall find that we are able to argue that the effect is due to certain motions and dispositions of the hypothetic ethers incidental to their gradual recovery from the condensation produced by the hypothetic force. In the present chapter we shall offer theories, reached by this line of reasoning, of the forces of attraction always found present in connection with all kinds of molecular matter, and known as *gravitation** and

* It is interesting to notice that, if we succeed in accounting for the force of attraction known as gravitation on first principles, without having recourse to the notion of action at a distance, we shall be realizing an expectation of the great Newton, the hold of which on his mind is indicated by the following passage, taken from a letter written by him to Bentley :—"It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other matter without mutual contact, as it must do if gravitation in the sense of Epicurus be essential and inherent in it. . . . That gravity should be innate, inherent, and essential to matter, so that one body can act upon another at a distance, through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it."

capillary action:—*Magnetic and electrical attraction and repulsion*, which, as far as their manifestation in any appreciable degree is concerned, are forces peculiar to particular bodies, or to particular conditions of bodies, will be dealt with subsequently.

The following general proposition, based upon our fundamental hypotheses, and upon the conclusions from them which we have arrived at above, contains, it is submitted, the principle lying at the root both of gravitation and of capillary attraction.

If, in a molecular body, the conditions are such that the un-molecular ethers which are present within it, as above supposed (see p. 27), have their density continuously greater in any given direction, the body will, as the result of the wave motions everywhere traversing matter (see p. 24), tend to move in this direction ; i.e., in the direction in which the most rapid increase of density of the un-molecular ethers is found.

The proof of this proposition which we have to offer is as follows :—

According to the above theories, all molecular matter, even that in the gaseous state, is restrained by the cohesion of its denser portions from the freedom of movement we have attributed to the un-molecular ethers, and, therefore, the molecular framework of any given body will not participate fully in wave movements or other motions undertaken by the un-molecular ethers occupying its interstices ; just as in a sponge, filled with water, small motions of the water are not fully participated in by the matter of the sponge. Consequently the molecular surfaces within the body, at which the molecular matter is in contact with the contained un-molecular ethers, will continually experience the passage past them, in various directions, of the un-molecular ethers, as the latter make small local wave movements* or other motions.

* See p. 24.



But, by hypothesis, some degree of cohesion or adhesion subsists between the molecular surfaces within the body and the unimolecular ethers which thus pass and repass them continually, and therefore, each time a small motion takes place of the unimolecular ether in contact with any portion of molecular surface, the molecular matter will experience a force tending to move it in the direction taken by the ether.

Where the ether movements are of the nature of waves of some kind, the *force* experienced at any point tending to move the molecular matter in a particular direction, will generally, it is evident, be succeeded by a force acting in the opposite direction ; but it is not necessary, or indeed possible, to suppose such opposite forces in every case equal, and we conclude that, as the result of the numberless small forces thus applied by the fluctuating ethers at all points of the molecular surfaces within the body, a slight degree of displacement of the body as a whole, in some direction or other relatively to the general mass of unimolecular ethers permeating it, will continually be taking place.

Now, and this is the keystone of our argument, the *amount* of displacement thus from time to time taking place, depends, not only on the nature and extent of the ether motions which produce it, *but also on the amount of cohesion or adhesion subsisting between the molecular surfaces and the unimolecular ethers which pass them* ; for this determines how far an ether motion of given extent shall be communicated to the molecular matter. In other words, the amount of displacement *depends on the density of the unimolecular ethers*, since, by one of our hypotheses, cohesion is regulated by density.

Therefore, a small displacement due to a certain series of ether movements *will be a maximum when it occurs in the direction of greatest density of the unimolecular ethers.*

And, finally, it follows from this that as ether motions must be supposed to take place equally, on the average, in all directions, their effect on a molecular mass will be greatest in the direction in which the ether density is greatest, and the resultant displacement, with respect to the general mass of unimolecular ethers, will have this direction. Our proposition is therefore established.

To establish the probability that both gravitation and capillary attraction are examples of the displacement of molecular masses with respect to the unimolecular ethers they contain, thus brought about—that they are the offspring of the drag of the minute ether surges on the molecular matter past which they play—we shall argue the existence of conditions of graduated ether density in the case of each of these forces, such as, according to the above proposition, would account for the precise phenomena observed.

First, as to the existence of gradation of density of the unimolecular ethers adequate to produce gravitation.

We have supposed that every detached molecular mass is liberating unimolecular ethers which pass away on all sides, and if, as we have concluded from the supposed constitution of molecular matter (p. 27), all molecular masses have complete porosity for the passage through them of unimolecular ethers, the radiations of unimolecular ethers, thus taking place, will communicate their motions both through space destitute of molecular matter, *and through the interstices of the molecular masses they encounter*.*

Now, whether the moving ethers are passing through space void of molecular matter, or traversing the interstices of the mass from which the radiation is taking place, or those of some other molecular mass, it is evident that,

* We have supposed that the unimolecular ethers within molecular masses maintain a high density as compared with ether in space destitute of molecular matter (see p. 27).

owing to their elasticity of bulk, their density will continually diminish as their distance from the centre of radiation increases.

And, therefore, as an effect of the supposed ether liberation, we have a falling gradient of density of the unimolecular ethers, outward from the molecular mass from which radiation is taking place, *i.e.*, in the direction in which, according to the above proposition, the gradient should fall, to account for a force of attraction towards this molecular mass.

In answer to the evident objection that the continual motion of translation of the unimolecular ethers which are thus furnishing a gradient of ether density *will produce a force of repulsion* so far as the molecular surfaces in contact with the unimolecular ethers partake of this motion of translation, it is urged that the amount of the ether motions occurring in passing waves may be far greater than the amount of the ether motions of translation; so much greater, indeed, that the force of repulsion due to the latter may be altogether inappreciable compared with the force of attraction which results from the former.*

With reference to the remarkable law discovered by Newton, that the force of attraction exerted by a body on another body varies inversely as the square of the distance :—

If our theory is sound that the attraction of gravitation is the result of the cohesion or adhesion subsisting between the molecular surfaces in the interior of bodies and the unimolecular ethers in contact with these surfaces, and we suppose that in cases where the law of Newton holds the repulsive force due to the motion of translation of these ethers is inappreciable and accordingly neglect it, it would evidently appear from the existence of Newton's law that

* There is some evidence of repulsion by the sun of bodies coming into near proximity to it.

where various detached bodies are exerting mutual attractions of gravitation, the degree of cohesion or adhesion subsisting at different points between the internal molecular surfaces of one of them and the unimolecular ethers in contact with these surfaces follows the law of Newton, *i.e.*, is in the ratio of the resultants of the various forces of gravitation, emanating from all the detached bodies exerted at these different points respectively.*

Now, according to one of our fundamental hypotheses, for the cohesion of the unimolecular ethers throughout a unit of surface to vary as $\frac{1}{l^2}$, the density of these ethers must vary as $\frac{1}{l^3}$, and therefore we conclude that the subsistence of the relation between the values of the cohesion at different points, just argued, indicates that the density conditions of the unimolecular ethers prevalent at any place are the result of concurrent ether radiations from the various centres of attraction such as would, if each were taking place alone, respectively give the ether density† in the inverse ratio of the cube of the distance from the centre of radiation.‡ To speak more explicitly, it indicates that the gradation of density of the unimolecular ethers present in each mass, and which, according to our theory, is the source of the movement of this mass which actually occurs, is, both as to direction and gradient, *the resultant* obtained by the composition of gradations of ether density

* In stating this we, of course, leave out of account any change in the relative positions of the detached bodies occurring from time to time, and treat them as fixed bodies.

† We have concluded that at all points the ether density is fluctuating in value owing to the passage of waves of alternating compression and expansion, and therefore what is meant here is that *the average* ether density varies according to the law stated.

‡ This relation would evidently involve the velocity at which the ethers travel varying directly as the distance from the centre of radiation.

which would respectively be produced in this mass if ether radiation from each of the various attracting centres, following the law just referred to, took place by itself. *

Towards accounting for the kind of radiation of the unimolecular ethers which we have thus argued must obtain for the law discovered by Newton to exist, we have to offer the following :—

It is reasonable to conclude that any radiating ethers will, on account of their viscosity, move unitedly in such a manner as to produce the least possible amount of re-arrangement of their particles.

When they are traversing space destitute of molecular matter, and supposing radiation to take place from one centre only, this requirement will manifestly be met, indeed the ether expansion will take place without any re-arrangement of particles whatever,—if all the linear dimensions of every small mass of ether radiated varies as its distance from the centre of radiation, *i.e.*, if, in other words, the density of the ethers varies as the inverse cube of the distance from this centre.

When radiating ethers are traversing the interstices of molecular matter, frequent re-arrangement of some of their particles will, it is evident, take place, and, when radiation takes place from more than one centre, ether accumulation must occur at some places and produce some degree of modification ; but the argument that the ethers will move unitedly in such a manner as to produce the *least possible* amount of re-arrangement of their particles will nevertheless still apply, and we shall therefore be justified in expecting that whatever ether motions take place they will very approximately be in conformity with the law just referred to.

* It is easy to see that if this is so the paths of the moving ether particles will, if produced, meet in a point, and that the resultant gradation of density, just referred to, will follow the law of inverse cubes with reference to this point as centre.

Such is the theory we offer of the origin of such gradients of ether density as would account for the force of gravitation varying inversely as the square of the distance.

Some significant facts may be mentioned in connection with the theory of gravitation which has been submitted above.

Messrs. G. H. Darwin and H. Darwin have made some refined experiments, showing that a freely-hung pendulum, however carefully protected from disturbing causes, is in a state of continual oscillation, and this *although the instrument used was found practically insensible to the effect of local tremors*. They have also found that such a pendulum is subject to a diurnal oscillation, and to a gradual change of the mean diurnal position. Again, M. Plantamour has called attention to what appears to be a periodic rise and fall of the ground in Switzerland, which he regards as associated with changes of temperature of the earth's surface. And, finally, Prof. Naudin has recently observed a lowering of the level of the Mediterranean at Antibes (Alpes Maritimes) which amounts to 30 centimètres. He believes its cause to be volcanic, but Dr. Faye, of Paris, connects it with high atmospheric pressure.

It is suggested that a probable explanation of these and of other similar facts is, that slight changes in the force of gravitation are produced by the occurrence from time to time of slight departures from uniformity in the ether liberation to which we have attributed the production of a gradation of ether density. To account for the diurnal changes referred to, we suppose that the ether liberation of the earth is affected by the position of the sun, whose power of causing ether liberation will be referred to hereafter.

Next we may mention the important fact that, in different localities, the direction of gravitation manifests various different aberrations from the strictly vertical.

The received theory that the force of gravitation resides in each particle of the substance of the earth, and that the amount of attractive force emanating from different points is proportional to the density at such points, has naturally led to an endeavour to explain these local aberrations of the direction of gravitation by the outline of the earth, or by the distribution of the different substances of various densities which compose it. Thus, it has been customary to refer any local aberration from the vertical, that is, from the line through the earth's centre, found in the direction of gravitation to the force of attraction of some neighbouring mountain or elevation of the earth's surface; and if no mountain was present, and the nature of the ground surface gave no encouragement to such an explanation or appeared to contradict it, then refuge has been taken in the supposition that the arrangement of masses of greater or less density *beneath the earth's surface* is such as to produce the observed variation.

The theory of gravitation which has been propounded points to an entirely different explanation. We are not concerned with the general outline of the earth's surface in the locality under consideration, or the disposition of rocks of different densities, but with the nature of the ether liberation in this locality; for on this, we suppose, depends the direction of the steepest gradient of ether density, and consequently the direction of gravitation.

Probably the direction of the steepest gradient of ether density at any point will be affected by the relative proportions of the two ethers evolved around this point; an aberration from the vertical being produced if the proportions of the two ethers being evolved on one side are very different from the proportions evolved on the opposite side. And if this is so, it seems probable that the proportions of the two ethers evolved from water on the one hand, and from rocks and soils on the other, differ

considerably, for we find that the most marked aberrations of the direction of gravitation are commonly found at localities near the sea. To mention an example:—At a very exceptional station on the north coast of Banffshire, near the village of Portsoy, the deflection amounts to as much as $10''$, and there are no adequate surface conditions of the undulating country near to account for any such aberration, upon the basis of the common assumption above alluded to.

Some pendulum observations made in India are in harmony with these views.

Thus the mass of rocks constituting the Himalaya mountains is not found to produce the deflection which their bulk would, according to the customary theory above referred to, lead us to expect ; so that it has actually been stated as proved that the density of the strata of the earth's crust under and in the vicinity of these mountains is less than that under the plains to the south.

Interesting facts have been by the same observations brought to light with regard to the relative variations of gravity at continental, coast, and island stations, it being found that, without a single exception, gravity at the coast stations is greater than at the corresponding continental stations, and greater at island stations than at coast stations.*

It is not, however, intended to convey that the configuration of the land has no effect on local attraction ; it is simply suggested that its only effect consists in any modification it produces of the direction of the steepest gradient of ether density.

The fact that the amount of movement of a body caused by gravitation is, as our theory would lead us to expect, independent of the density of the body, is well shown by the familiar experiment of simultaneously letting fall a

* “Encyclopædia Britannica,” Art., “Fig. of the Earth.”

sovereign and a feather in vacuo, when it is found that the two different bodies fall in the same time.

Finally, we may refer to the fact of very different densities having been deduced for the various heavenly bodies upon the received theory that the attractive force they exercise resides in their particles, and depends on their respective masses; *e.g.*, the density of Jupiter is calculated to be about one-fourth that of the earth.

As the above theory, instead of making the attraction depend on the mass of the attracting body, makes it depend on the amount of radiation of unimolecular ethers, proceeding from this body, *no such differences of density of the heavenly bodies need be supposed, according to this theory, and we thus escape the difficulty of reconciling the existence of such differences with the modern discovery of the similarity of constitution of so many of the heavenly bodies.*

As to the connection between weight and gravitation. According to the above theory the weight of a body will, it is manifest, be expressed by the number of units of molecular surface there are within it, a unit of molecular surface being the extent of surface which has unit cohesion with the unimolecular ethers. The number of such units in any particular body will, it is evident, vary according to the density of the unimolecular ethers within it. In accordance with this the weight of a body depends on its distance from the earth or other attracting body.

Capillary Action.

Capillary action takes its name from the behaviour of water or other mobile fluid in a very small tube, so small as to be comparable in internal calibre to the size of a hair. It is found that when such a tube open at both ends is lowered endways into water, the water rises within the tube to a higher level than the water outside.

The existence at the surfaces of bodies of a gradation of density of the unimolecular ethers adequate, according to the general proposition submitted at the commencement of this chapter, to account for the phenomenon of capillary attraction, follows at once from our supposition (p. 27) that the density of the unimolecular ethers present within molecular masses is to some extent proportionate to the density of the atoms composing these masses. For, if such is the case, then, wherever a dense body is surrounded by a vacuum, or by a medium whose density is not so great as its own, there will be a sudden fall of density of the unimolecular ethers from the interior of the body, across its bounding surfaces, into the medium outside it, and we shall have along all such surfaces a steep gradient of falling density of these ethers extending from some, probably very short, distance within the body to some, probably very short, distance outside it.*

And, as supporting this, we may cite the discovery made by Quincke, that for several series of substances the capillary force at the surface is nearly proportional to the density.

The following, based on the theory of capillary attraction thus completed, is our explanation of the rounding off of what would otherwise be the angles and edges of the free surfaces of liquids, and the softening of their outlines; phenomena which, since the middle of the last century, have been attributed to a surface-tension, because the contours presented are such as can be produced by a uniform stretched membrane.

We have argued that forces of displacement of molecular matter caused by gradations of density of the unimolecular ethers always follow the directions in which the most

* It may be mentioned that Poisson maintained that there is a rapid variation of the density near the surface of a liquid, and that this conclusion has since received confirmation.

rapid increases of density of these ethers are found, and it follows from this that such forces everywhere act perpendicular to surfaces throughout which equal density of the unimolecular ethers prevails ; consequently, *every small portion of the free surfaces of any liquid mass will be found coinciding as nearly as the subsisting conditions of the matter of the mass generally will allow, with some such surface of uniform ether density.*

But since the density of the unimolecular ethers at any point on the boundary of a molecular mass will depend on the conditions of ether density prevalent for some distance around this point, it is evident that the value of this density at such a boundary will, where the structure of each of the molecular masses meeting at this boundary is uniform, vary according to the contour of the surface around the place of observation. Thus, on a projecting portion of the mass, this value will be relatively lower if the ether density within the mass is higher than the ether density outside it, relatively higher if the contrary is the case ; and, on the other hand, in a depression of the general surface, this value will be relatively higher if the ether density within the mass is higher than that outside it, relatively lower if the contrary is the case, *and therefore in the case of a mass of liquid, bounded by a free surface, this surface will not be in equilibrium, and will consequently experience change so long as it has not a certain definite form which gives the density of the unimolecular ethers as uniform as possible throughout every small portion of it.*

The nature of the surface in which equilibrium is thus reached will evidently depend on the ether conditions prevalent in the liquid, and in the medium outside it, and also on any modifying effects produced by gravitation, the presence of solid boundaries, or other causes.

In the case of a mass of liquid, surrounded on all sides by some uniform fluid, and free from any external modify-

ing conditions, equilibrium will be reached only when the bounding surface becomes spherical.

In harmony with this conclusion we have the following familiar fact:—

When any falling mass of liquid has broken up into fragments, owing to its particles not being capable of rearrangement with sufficient rapidity to allow the continual elongation of the mass by the action of gravitation to proceed without rupture, the fragments, after a series of oscillations of form, settle down to a spherical shape.

We may also refer to an experiment of M. Plateau with two liquids of the same specific gravity. After forming a mixture of alcohol and water of the same specific gravity as olive oil, he introduces a quantity of the oil into the mixture, when, if no modifying conditions are present, the mass of oil suspended within the mixture assumes a spherical form.

Here we argue from the fact of the two liquids, the oil and the mixture of alcohol and water, not diffusing into each other that their respective particles at any place where they touch do not interlock as the result of the motions which, according to the previous arguments, they are continually making, *so that there is where they meet a narrow space but little intruded upon by the dense matter of the liquids*. For, if the particles of different kinds did to any considerable extent come into close contact, we conclude that diffusion would take place through the operation of the law of symmetrical intermixture (p. 38).

Now, if there is at the boundary between the two liquids this narrow space comparatively clear of molecular matter, a double gradation of density of the unimolecular ethers will, according to the above theory of capillary attraction, subsist, *i.e.*, a falling gradient of density from each liquid into this intervening space, and the explanation given above will apply, and the spherical form taken by the mass

of oil be attributable to the surface of each liquid finding equilibrium in this form. *

Next we will call attention to one or two examples of the application of the above explanation to cases where a mass of liquid has its general form modified by gravitation, and contact with more than one kind of substance.

Thus the following is the explanation submitted of the familiar fact that a drop of one liquid placed upon the surface of another liquid in many cases—*e.g.*, in the case of a drop of melted fat placed upon water—assumes the form of a lens, and does not spread itself over the surface in a film of growing tenuity as its attraction to this surface seeks to make it do, and as is seen in some other cases.

The force of capillary attraction present near the surface of the one liquid, which tends to spread out the drop of the other liquid placed upon it, is on the one hand reinforced by the gravitation of the drop, and on the other hand opposed by the endeavour of the drop to take a spherical form, caused, as above explained, by the capillary force at its surface.

The resultant force thus subsisting, which acts primarily on the particles of the drop lying within range of the capillary action of the liquid surface on which it rests,

* An experiment made by M. Duprez brings out the resistance to change of form subsisting at a surface between two liquids which do not diffuse into one another. He places a vessel containing olive oil with its mouth downwards in a vessel containing a mixture of alcohol and water, the mixture being denser than the oil. The surface of separation is in this case horizontal and stable, so that the equilibrium is established of itself. Alcohol is then added very gradually to the mixture till it becomes lighter than the oil. The equilibrium of the fluids would now be unstable if it were not for the resistance referred to, and which, when the orifice of the vessel is not too large, continues to preserve the stability of the equilibrium.

When the equilibrium at last becomes unstable, the destruction of equilibrium takes place by the lighter fluid ascending in one part of the orifice and the heavier descending in the other.

and tends to spread the drop, *will, it is evident, begin to fall in value as the drop spreads slightly when first placed upon the surface* ; for the effect of gravitation, which aids in spreading the drop, will diminish as the vertical height diminishes, and at the same time the capillary force acting on the surface of the drop, which opposes its spread, will increase as its form departs more and more from the spherical.

Now this diminishing resultant force is resisted by the viscosity of the liquid composing the drop, and it is suggested that in the cases under consideration, *when the drop has spread to a certain limited extent, this resultant is thereby brought down to a critical value at which it is just too small to overcome the viscosity, i.e., the resistance of the liquid to the relative motion of its parts, and so no further spread of the drop takes place.*

When this state of equilibrium is reached, and we have taken into account the displacement by the drop of a portion of the liquid upon which it floats, the extent of which will depend on the comparative specific gravities of the two liquids, we may evidently conclude that at every point in some surface intersecting the lower portion of the drop, throughout which the resultant force of displacement is a maximum, this force has the critical value just referred to, *the general distribution of the matter forming the drop being in this way determined.*

Finally, the precise curvature of surface presented in such cases is evidently referrible to the capillary force at this surface ; this force, according to the above argument, producing such a form as will give the density of the unimolecular ethers as uniform as possible, consistently with the above, throughout every small portion of surface.

In harmony with the above conclusion, that the general distribution of the matter forming the drop, that indeed its continuance as a drop, is determined in any given case by

the viscosity, we have the fact observed by Andrews that the capillary action becomes weaker as the temperature rises, and vanishes at the critical point at which the distinction between the liquid and its vapour ceases.

In proof that the capillary force seeking to spread the drop depends on the kind of molecular matter *present within a very thin stratum* at the surface on which it floats, we have the interesting fact that when a drop of train oil placed upon a large body of water has spread out into a film of infinitesimal thickness, *i.e.*, when so thin that it ceases to produce interference colours, its presence causes a second drop placed on the surface to remain gathered up in a lens shape with a distinct circular edge.

The same line of argument as we have just offered will apply to the familiar phenomenon of a liquid remaining in equilibrium though its surface stands slightly above the edge of the vessel containing it. Also to the case of a drop placed upon a solid surface. It should be observed, in connection with the latter case, however, that where the density of the unimolecular ethers within the drop is very great, the value of this density at and just below its surface will be almost as great where the liquid adjoins the air as where it adjoins the solid, and the capillary attraction exercised by the solid will consequently be small. It is suggested that this is why small drops of mercury placed on most solids take a nearly spherical form, the capillary action at the surface of the mercury having almost nothing but the gravitation of the liquid metal to oppose it.

The familiar fact that with most liquids the free surface where the liquid meets the side of a vessel which rises above it, curves upward, so that at its edge the liquid stands rather higher than elsewhere, is explained as follows :—

We suppose that where this is the case the density of the unimolecular ethers present within the substance of the

vessel is greater than the density of those within the liquid. The consequence of this will be that at, and just below, the general surface of the liquid which lies against the side of the vessel, the ether density will be higher than it is at the free surface; and, therefore, that surfaces of uniform ether density lying at and just below the general free surface of the liquid will not extend in the same plane up to the surface of the vessel, *but will turn upwards near to it*. And, consequently, if it were not for the falling off in ether density, which we have concluded exists in any projections of a mass (p. 51), thin films of liquid projecting upwards from the general surface next the sides of the vessel would have the ether density within them as great as that subsisting at and immediately beneath the general free surface of the liquid, and would therefore be in equilibrium.

That in the cases under consideration the liquid merely curves upward slightly at its edge, and does not form these thin films, we attribute then to the form of the surface, where the liquid projects upward at its edge, causing the density of the unimolecular ethers to be lower in the projecting portion; the combined result of the capillary action of the surface of the vessel, and that of the surface of the liquid, being that the surface of uniform density of the unimolecular ethers, which coincides with the general free surface of the liquid, after passing upwards a little near the edge, *turns and passes down again to join the surface of the same density lying parallel to the side of the vessel a short distance within the liquid*.

The curvature of the liquid surface will, as before, be such as gives the density of the unimolecular ethers as uniform as possible throughout any small portion of this surface.

The rise of a liquid in a capillary tube, of which the accompanying diagram represents an exaggerated section, we refer to the effect of a high density of the unimolecular ethers within the liquid near the surfaces of the

tube, produced as above, in giving a relatively higher ether density within the tube at the level of the general surface. For the consequence of this will be that for the surface of the liquid to follow a surface of uniform ether density, it will have within the tube to stand at a height above the general level such that the heightening of the ether density just referred to shall be just counterbalanced by the weakening of this density due to the projection beyond the general surface (see p. 51).

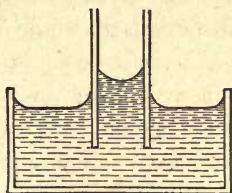


Fig. 1.

The explanations given of the previous case will apply to account for the precise forms taken by the surface.

That when a glass tube is dipped into a vessel of mercury, the mercury within the tube stands at a *lower level* than outside, would be similarly explained, if we suppose the density of the unmoolecular ethers within the substance of the glass to be less than that of those within the mercury. For if this is so, the intrusion of the glass will lower the ether density within the mercury close to the glass, and, for a surface of uniform ether density to be followed by the liquid surface as before, a depression of the portion of the latter within the tube must occur such as to give a strengthening of the ether density at this part of the surface (see p. 51) just sufficient to counterbalance the weakening due to the intrusion of the glass.

As an instance of the mutual effect of the capillary forces at the surfaces of two different liquids in contact in effecting change of form, we may refer to the fact that if a drop of alcohol be made to touch one side of a drop of oil on a glass plate, before equilibrium is reached under the capillary conditions thus produced, a considerable motion of the boundary between the two liquids in the direction from the alcohol to the oil takes place.

A similar effect is observed if a drop of water and a drop of bisulphide of carbon are placed in contact in a horizontal capillary tube, motion taking place in the direction from the bisulphide of carbon to the water.

To refer next to cases of changes of form of liquid masses where the capillary action emanating from solids with which they are in contact preponderates over the capillary action emanating from the liquids themselves :—

When a drop of water is introduced between two glass plates nearly in contact, slightly inclined to each other, it thins itself out as much as possible by running towards that part where the glass plates are nearest together, although, as we know, a drop of water in contact with a single glass surface does not become thinned out in this way. By way of explanation of this we observe that the fact of all the small portion of free surface present in this case having its ether density modified by the near proximity of the glass would cause the capillary force at this surface, which tends to prevent extension of the drop, to be very small, and thus would account for the preponderance of the spreading force exercised by the capillary attraction of the glass surfaces. The enormous force produced by the introduction of a drop of water in this way, which presses the plates together so powerfully as often to bruise certain parts of them, or to break them, is probably due to the close proximity of the surfaces of the two plates bringing all the water present between them to within an infinitesimal distance of the solid surfaces, and thus confining it to the place of steepest ether gradation and greatest capillary attraction ; and to small *continuous* portions of the molecular matter of the liquid* consequently experiencing at different parts of them at the same time powerful capillary attractions to *both* the opposing surfaces.

The instance of capillary action furnished by the familiar

* See p. 29 as to the supposed constitution of a liquid.

occurrence of a towel drawing the water out of a basin into which it dips will have a similar explanation to the above experiment with two glass plates. *

The phenomenon called the "tears of strong wine" may be mentioned in this connection. When a glass is partly filled with strong wine the liquid creeps up the side, and collecting into drops runs down again, and these drops are found to be more watery than the rest of the liquid.

The explanation suggested is that the capillary force at the surface of the strong wine is inadequate to prevent the spreading effect of the capillary action emanating from the glass, so that a thin film of the liquid rises up the sides ; that, as the alcohol in this thin film evaporates more rapidly than the water, the capillary force emanating from the liquid of the film increases, so that presently it is sufficient to overcome the capillary force emanating from the solid on which it rests, and begins to collect the liquid of the film in distinct patches of greater thickness ; and, finally, that this clears the greater part of the glass surface and allows further quantities of the strong wine to be drawn up ; the quantity of watery liquid growing from time to time, as the process goes on, into drops of sufficient magnitude to run down by gravitation.

The attraction of a floating body towards the edge of a liquid in cases where the edge curves upward, and the converse repulsion from the edge in cases where it rounds downwards, will both, it is evident, be referred to the production of different gradations of density of the unimolecular ethers, on opposite sides of the floating body, caused by the influence above explained of the form of the molecular surface of the liquid on surfaces of uniform ether density

* It is needless to say that for the towel to form a syphon, and let the water drop from the outer end, this end must be lower than the surface of the water, so that the weight of water in the portion of the towel outside may be sufficient to overcome the weight of that in the portion inside.

drawn at the boundaries of the floating body and the liquid on which it rests.

As different liquids will have different gradations of density of the unimolecular ethers at their surfaces, we should expect that when masses of two kinds of liquid contained in the same vessel have their free surfaces adjoining, a surface of uniform density, drawn at the surface of the general mass, will have irregularities, trending slightly upwards or downwards where it passes from one material to the other. And this appears to be the explanation of the fact that when a drop of alcohol is placed on the surface of water the equilibrium of the surface is changed in such a way that if the depth of the water is only two or three millimètres the surface current produced sweeps away the whole of the water, leaving a dry spot where the alcohol was dropped in. It will similarly explain the fact that if a drop of ether is held near the surface of water, the vapour of ether condensing on this surface produces surface currents flowing in every direction away from under the drop of ether.

It would appear to be owing to the effect just alluded to that if a small body floating in a shallow vessel of water has one side wetted with alcohol or ether, it moves off with great velocity, and skims about on the surface of the water with the alcohol at the stern.

Before we leave the subject of capillary action, a fact generally regarded as furnishing evidence of the existence of a surface-tension of liquids demands explanation at our hands:—

Liquid films whose surfaces are free, *i.e.*, in contact with gases, are found to have a tendency to contract. M. Dupré has described an arrangement by which this is illustrated.*

A rectangular frame formed of sheet metal, three sides

* Leidenfrost showed in 1756 that such a contraction occurs in the case of a soap bubble, the bubble diminishing in size if the tube with which it is blown be left open.

of which are continuous, and the fourth, a very fine strip, movable, is dipped into a solution of soap, or of M. Plateau's glycerine mixture, so that the space within the rectangle may become covered by a liquid film. It is then found that contraction of the film is occurring tending to slide the movable side of the rectangle upon the two sides adjacent to it.

The explanation we have to offer is as follows :—

First, as to the formation of the film.—As the frame is being lifted from the liquid the liquid runs off from it by the law of gravitation, aided at last by the capillary attraction found at the surfaces of the liquid ; but since the effect of these forces on the mass varies as its bulk, while the cohesion varies as its section, a point is presently reached when a continuous mass of liquid remains within the rectangle, the forces acting on which are insufficient to overcome the cohesion which links particle to particle, and the outside particles to the frame, and thus we have a thin film adhering to the sides of the rectangle. The time this film will last depends largely on its rate of evaporation ; if the evaporation is very rapid the film will be immediately destroyed.

Next, as to the contraction of the film.

The very perfect regularity of the surfaces of the film is evidently accounted for by its not finding equilibrium under the capillary action at these surfaces, until the form they take gives the density of the unimolecular ethers as uniform as possible throughout every small portion of surface (see p. 51). As, however, a number of local impulses are continually being imparted to the film by the wave motions and other small motions occurring in the gases in contact with it, and also in the unimolecular ethers found among its molecules, we must suppose that local temporary distortions of the film which elude observation are continually taking place.

Now, the capillary force just alluded to must, it is evident, as it acts on small temporary elevations or depressions of either surface, produce slight local fluctuations in the substance of the film, temporarily thickening and temporarily thinning it here and there.

If it were not for the evaporation of the film which, to a greater or less extent, is proceeding, it does not appear that local fluctuations of thickness thus produced would have any but a local and temporary effect, but since, as above suggested, the thickness of the film at the time of its formation is the result of a limit being reached, at which the cohesion of the particles suffices to resist the forces seeking to re-arrange them, we see *that motions which thin the film will experience more resistance than motions which thicken it, and that the net result of the local changes of substance, just referred to above, will be to thicken, and consequently to contract it.* The process of thinning the film by evaporation will consequently be somewhat retarded.

The very small distance from a surface to which any appreciable gradation of ether density, capable of producing capillary attraction, extends, is indicated by the observations of Quincke and others, who find that the extreme distance at which an effect is produced is from a thousandth to a twenty-thousandth part of a millimètre.

A reference to change of form of capillary surfaces produced by the presence of electricity, confirmatory of the above theories, will be found in the sequel (p. 123).

ELECTRICITY.

CHAPTER VI.

THEORY OF WHAT ELECTRICITY IS—CONDUCTION.

FAMILIAR as the phenomena of electricity have become to us all, the question, "What is electricity?" has hitherto remained unanswered. To some extent the same ignorance may be said to prevail of the two yet more familiar handmaids of matter, light and heat, but not altogether, for while no fundamental theory of electricity which has obtained at all general acceptance, has yet been offered, the latter are partially accounted for by accepted theories, more or less satisfactory.

As to all the three exhibitions of force, light, heat, and electricity, that they have an intimate relation to matter in all its forms, is evident, for they all may, by appropriate means, be evolved from all known kinds of matter; but they are generally rather regarded as in their origin external to it, or as imparted to it, and not as necessarily inhering in all matter.

We shall endeavour to show in this treatise that light, heat, and electricity are all, considered apart from the impression which they make on our senses (which impression is a function of our organization), *strictly inherent in matter*, the outcome of the fundamental properties we have ascribed to it;—that they are, in fact, motions, or changes of relative position made by the different masses

of ether, of which, according to our hypotheses, matter consists, as they seek equilibrium. The vehicle of communication of all three from place to place, we shall consequently argue, is found in the unimolecular ethers, and all their manifestations will be referred to the effects of the presence and movements of the unimolecular ethers on the above described molecular matter.*

Electricity is, it is suggested, the condition of molecular matter which is brought about by contact with a body of one kind of ether present alone; positive or vitreous electrification resulting from the presence of one of the two ethers (which we shall therefore call positive ether), negative or resinous electrification resulting from the presence of the other ether (which we shall therefore call negative ether).†

We shall now proceed to test the plausibility of this supposition, by showing how far it is consistent with and explanatory of many of the very various phenomena of electricity.

CONDUCTION AND NON-CONDUCTION.

The almost instantaneous communication of electrical effects from one point in space to another, *e.g.*, the passage

* An important part has been already assigned to the unimolecular ethers, in producing changes of bulk and changes of state; and these changes can, we know, in most cases, be referred to the action of light, heat, or electricity—generally to the action of heat.

† Dufay, more than a century ago, first discovered the existence of two kinds of electricity; and Symmer, in the last century, maintained the theory of two distinct fluids, not independent of each other, but coexistent, and, by counteracting each other, producing all the phenomena of electricity.

For a familiar means of distinguishing positive electricity from negative electricity, see p. 79. Some reasons will be subsequently given for believing that positive electrification is due to the presence of an excess of the *more readily compressible ether*; negative electrification to that of an excess of the *less readily compressible ether*.



of an electric current through thousands of miles of metal wire in a few minutes, is perhaps, to the casual observer, the most astounding of all the electrical properties, and is so contrary in its aspects to our usual ideas of the motions of matter, that although an electric "fluid" is commonly spoken of, it is not usual to regard it as a substance.

The difficulty of supposing it to be a substance is however, to some extent, obviated, if we regard the conductor as a reservoir already filled with electric fluid. For in this case we need not consider the almost instantaneous transmission of the effect from one extremity to the other to be evidence that matter which was present at the one end has all, or any part of it, actually passed to the other end, since it is no more necessary to suppose that the same electric fluid which flows in at the one end flows out at the other, than to suppose that, when more water is added to that within a receptacle already full, the overflowing drops are those, and those only, which are added.

We have already supposed that molecular matter in all the states in which it is presented to us is permeated by un-molecular ethers (see p. 27), that it is in fact, to some extent, a reservoir of un-molecular ethers,* these ethers preserving a density in some degree proportionate to the density of the atoms among which they are evolved. And, in harmony with this supposition, the explanation of conduction which we have to offer is,—

That ether of each sort, contained in and around the molecular matter of a conductor, is found capable of displacement by a stream of *similar*† ether, just as water in a pipe is displaceable by water poured in at one extremity

* Upon this supposition the foregoing theories of gravitation and capillary action are based.

† The reason for supposing that only the similar ether is thus displaced is given immediately.

of the pipe, and that, taking into account the incomparably greater mobility of unimolecular ether than of molecular liquid, a continuous stream of water trickling down the underside of some solid body may be regarded as the analogue of an electric current in a conducting wire; the motions of the fluid being in both cases due to the transmitted pressures being out of equilibrium.*

In thus explaining electrical conduction, there is one difficulty to be met, which has no doubt already occurred to the reader. If both ethers are present among the molecules of the conductor, why should not the entrance of a body of one ether at one extremity of the conductor displace both ethers equally, and produce a current at the further extremity, not of the same ether only, but of both ethers mixed as they occur in the conductor?

The reply to this important objection is based upon the hypothesis that the two ethers expand at different rates, and is as follows:—

If conduction is of the nature just suggested there must in a conducting body be a continuous chain of ether particles simultaneously displaceable in the direction of the current. Now, the local fluctuations of density due to passing waves, which we have argued that all matter, in whatever state, is continually undergoing (p. 25), will, since by hypothesis one ether is more readily compressible than the other, continually alter the arrangement of the particles of one ether relatively to the particles of the

* The capillary action of a piece of string, when it empties the water from a vessel into which it dips, will furnish a still better illustration.

It may be mentioned that the passage of an electric current, caused by disturbance of electrical equilibrium, has often been compared to the flowing of water from a higher to a lower level, *e.g.*, in the case when, on an electrified ball being placed in contact with a precisely equal and similar unelectrified ball, the charge becomes equally divided between the balls.

other, but they will not materially alter the relative arrangement of the particles in any given mass *composed of one kind of ether only* except at its boundaries, where it is in contact with the other ether. And therefore the transmission of pressure through a mass of ethers will encounter a perpetual succession of checks in seeking to pass from one ether to the other, and be indefinitely retarded, but will take place instantaneously through considerable distances where one ether only is present.

Consequently, where ether pressure applied at one end of a conductor finds a continuous mass of one ether unmixed with the other, it will be transmitted almost entirely through this mass, and not to any perceptible extent through any mixed ethers which are also present.*

To account for the presence of continuous chains of particles of each ether unmixed with particles of the other ether in conducting bodies, such as this explanation presupposes, notwithstanding the existence of the law of symmetrical intermixture, we suggest that in all bodies small masses of intermixed unimolecular ethers are continually here and there temporarily separated into their constituents by the disturbances to which we suppose all matter to be continually subjected, and that the composition of conducting bodies is such that re-intermixture does not take place so readily in these bodies as in non-conductors ; and, further, that minute imperceptible ether currents are everywhere continuously traversing all conducting bodies, whether they are apparently electrified or not. Of the latter supposition some evidence will be submitted subsequently.

* We shall argue presently that, so far from the entrance of one kind of ether at one extremity of a conductor producing a flow of the other kind of ether out from the other end, the flow of one ether in one direction in a conductor invariably produces a flow of the other ether in the opposite direction as a consequence of the law of symmetrical intermixture (see p. 75).

The above suggestion, that unbroken continuity of one ether upon the surface or within the interstices of the conducting body is indispensable to good conduction, receives some experimental confirmation.

Thus we have the fact that more force is requisite to start a current than to maintain it, Varley having found, in passing an electric current through a Geissler's tube, that it required 323 cells to start the current, but that to maintain it 308 cells were adequate. And this, in terms of the above theory, indicates that the flow of a stream of ether between two points is facilitated by a favourable disposition of the ethers between these points.*

We have, too, a fact pointing in the same direction, which is analogous to the fact that different portions of a stream of water, owing to their experiencing different retardation by friction, move at different rates. In a very long conductor, a long submarine wire for instance, a short, sharp signal sent in at one end comes out at the other as a signal gradually increasing from nothing to a maximum, and then gradually dying away. And this evidently indicates that the electrical condition of the wire is gradually produced, and also that this condition continues with a gradually diminishing intensity for a short time after the producing cause has ceased to act.

Further, we may cite the elementary fact that positive and negative electricity tend to neutralize each other, so that if a conductor receives two charges of electricity of equal† quantity but opposite sign it exhibits no trace of electricity whatever. For we may suppose that symmetrical intermixture of the two ethers occurring, as already argued, when they come together (see p. 9), *each*

* A striking confirmation of this is found in the necessity of a condition of preparedness of the voltaic arc, referred to in the sequel (see p. 196).

† We ought, perhaps, rather to say "commensurate."

ether, when the intermixture has taken place, continually breaks the continuity of the other as passing ether waves cause them to expand or contract at different rates, and that each ether in this way prevents the motion of the other, except so far as the insensible ether motions above referred to are concerned.

From this it would follow that it is the difference and not the sum of the two ethers present at one spot which ordinarily determines the amount of electric force exhibited.*

Finally, as furnishing corroborative evidence of the above suggestion, we may refer to the facts as to the various degrees of conductivity found in matter in different states and of different kinds.

Thus, if unbroken continuity of one ether is essential to good conduction, we should expect those bodies in which there is least molecular vibration or disturbance to be the best conductors, those in which there is most the worst.

Now, in the case of most of the elements, the solid state is characterized by the highest conductivity, the liquid state by the next highest, and the gaseous state by the lowest;† and according to our theories as to the nature of these states, which theories are supported by the respective characteristics of the states, the amount of intermolecular motion they severally have follows just the inverse order, *i.e.*, there is least motion in the non-cellular solid state, considerably more in the liquid state, most of all in the gaseous state.

* We shall endeavour to show hereafter that the effect of the *intermixed* unimolecular ethers on molecular matter with which they come in contact belongs to another branch of physics; that it is a phenomenon of heat and not of electricity (see p. 302).

† The relative conductivity of metals is generally considered to be determined by the relative amount of resistance which they exhibit to an electric current (see p. 151).

And again,—Bodies which from their optical* and other properties we shall see reason hereafter to conclude are in the cellular solid state, are bad conductors. And this is explained, if we suppose that the ready transmission of ether waves, which we shall argue characterizes substances in this state (p. 269), is attributable to the readiness with which the cellular mass moves in obedience to wave motions which traverse it, and that the vigorous wave vibrations transmitted through matter in this state produce rupture of continuity in each ether permeating it. It seems likely, however, that when, as in most cases, such bodies are *chemical compounds*, it is to want of unison in the pulsations of small masses of different elements which lie next one another,† arising through their different compressibility, that rupture of continuity of the unimolecular ethers is chiefly due.

Of the substances we suppose to be in the cellular solid state which are bad conductors, we may mention shellac, jet, glass, diamond, silk, wool, feathers, marble, chalk and lime.

Most chemical compounds, when fused or in solution, show rather rapidly increasing conductivity with increase of temperature. On the other hand, the conductivity of metallic conductors would appear to diminish, but more slowly as the temperature rises (see p. 303).

The explanations given above apply to differences in *surface conductivity*. Thus, we suggest that the reason why electricity will not pass along the surface of polished glass as readily as along the surface of polished metal, is that the surface of the glass, as well as its entire substance, is in such a state of continual minute vibration that ether-

* See p. 272.

† Chemical compounds are hereafter argued to be symmetrical intermixtures of infinitesimal equal masses, or secondary atoms of different elements.

continuity of each ether in the body of dense unimolecular ethers coating the surface* is perpetually broken.

As we should expect if the cause of non-conduction is that suggested, the efficacy of a non-conducting body or insulator is increased by diminishing its perimeter and increasing its length ; for example, a long fibre of glass or raw silk is an excellent insulator.

Since our arguments trace the insulating power of a body to broken continuity of each of the ethers within it, produced by molecular motions, it does not surprise us to find that although ordinary air is a good insulator, highly rarefied air is a conductor, that in fact while increased pressure increases dielectric strength, diminished pressure decreases it. For it is reasonable to expect that as the molecules of the gas become more expanded and less numerous, they will have less power by their vibrations to break the continuity of currents of unmixed ether seeking to traverse the gas. As to the important fact that a limit to the operation of this law is presently reached, so that when special means are employed to render the vacuum as nearly perfect as possible, the resistance increases so much as to prevent any observable discharge, we may hazard the suggestion that discharge is not prevented, as at first appears, but that *the current which passes is almost infinitesimal in quantity because the ether which it displaces has extreme tenuity.*

The reason that the track of the discharge becomes at last invisible or non-luminous, we suppose to be that the amount of molecule destruction is inconsiderable when the quantity of molecular matter present has become infinitesimal, molecule destruction, *i.e.*, atom explosion, being in the sequel supposed to be the producing cause of the waves which propagate light.

The fact that very hot air is a conductor will appear

* See p. 50.

explicable when in the sequel we trace the presence of heat to the exhibition of a large quantity of the unmolecular ethers (see p. 302).

That negative charges are generally dissipated, without a parent conduction, more readily than positive charges, is perhaps due to the same waves producing less motion in one ether than the other, so that under the same conditions ether continuity is more broken in one ether than in the other.

CHAPTER VII.

ELECTRICS AND NON-ELECTRICS.—ELECTRICITY LIBERATED BY MOTIONS OF MOLECULAR MASSES.—THE TWO ETHERS MOVE IN OPPOSITE DIRECTIONS.

IT is a matter of experience that patches of electricity may lie upon a surface of glass, or of some other non-conductor, without travelling away by conduction, and this produces the distinction between electrics and non-electrics, for while it is well established that electricity can be developed by the friction of any substance, it is ordinarily obtainable from non-conducting substances only because it passes away insensibly, as it is generated, when it is developed by friction of a conducting body.*

A very suggestive experiment first devised by Lichtenberg seems to show that different substances are, in their normal condition, undergoing molecular disintegration, and emitting some an excess of one, others an excess of the other kind of ether, and at the same time throws light on the nature of deposits of positive and negative ethers upon a non-conducting surface.

If the knob of a charged Leyden jar is drawn over the surface of a plate of shellac or vulcanite, the outside coating

* In a communication to the Royal Society of Edinburgh, in Jan., 1879, James Blyth, M.A., F.R.S.E., showed that electric currents were produced by the mere friction between conducting substances.

The passing away of electricity from a conducting body, when the body is not insulated, is simply an instance of the property displayed by electricity of distributing itself at the external boundary of a conductor, or system of connected conductors, to which reference is made presently (see p. 88).

being connected with the earth, patches of positive electricity are deposited upon the surface. If on the other hand the outside coating is drawn over such a surface, while the inner coating is connected with the earth,* patches of negative electricity are similarly deposited. And when a mixed powder, consisting of flowers of sulphur and red lead, is afterwards shaken upon the plate, the sulphur adheres to those parts of the surface upon which positive electricity is deposited, and the red lead to those upon which negative is deposited, the result being very striking, the branching lines of the positive deposits and the circular spots of the negative deposits revealing very marked difference in the behaviour of the two electricities.

The suggested explanation is that the sulphur is emitting an excess of negative ether, the red lead an excess of positive, and that a selective action of the two different ethers upon these two substances arises in consequence, according to the well-known laws of attraction, between diverse electricities.†

Our supposition, that atoms are composed of the two ethers, which is thus countenanced, is also supported by the facts that electrification is caused by pressure, by cleavage, and by rupture; for if we suppose these agencies to produce atom explosion, we shall, according to the composition of the atoms exploded, look for the presence of an excess of one ether or the other among the undestroyed atoms.‡

We will next offer an explanation of the fact that electricity is producible in very considerable quantities by friction.

The first step towards this is the establishment of the

* When the operator changes his hold upon the jar from the outside coating to the knob, he must, of course, place it upon an insulating stand.

† These laws will be investigated presently.

Further evidence in the same direction is furnished by the facts of voltaic electricity.

following important theorem, which will be subsequently referred to as *the law of opposite currents*.

If masses of the two ethers are present, unmixed, in contact with each other, the passage of one ether in a particular direction directly operates to produce the movement of the other ether in the opposite direction.

The proof, which immediately depends on our conclusion that the motion of one ether has no appreciable effect in producing motion of the other ether *in the same direction*, coupled with the law of symmetrical intermixture, is as follows :—

As the result of the law of symmetrical intermixture, if masses of the two different ethers are side by side, each will pass towards and inter-penetrate the other ; in other words, they will pass in opposite directions.

But the ethers which do not directly intermix, are, by cohesion, attached to, and therefore carried along with, those which do, and since, as we have argued, the fluctuations everywhere occurring which produce intermixture, do not materially alter the relative arrangement of the particles within any small mass *composed of one ether only*, but do continually alter the arrangement of the particles of one ether relatively to the particles of the other, each ether engaged in the act of intermixing will carry with it ether of the same kind, which, for the moment, remains un-intermixed, *in preference to ether of the other kind*.

And therefore, in all cases where masses of the two ethers are present, unmixed, in contact with each other, the two ethers will move in opposite directions, both those which are in the act of intermixing, *and those which are not*, and the law just stated is established.*

To apply this law to the subject under consideration—the production of electricity by friction.

* The fact of the flow of the two electricities in opposite directions

The same argument which has just been used to show that when one of the ethers is in motion it will carry with it ether of the same kind, rather than ether of the other kind, can be applied to show that a molecular mass, in which the atom explosion occurring is liberating an excess of one ether, will, when in motion, carry with it ether of this kind rather than ether of the other kind. Consequently, if two substances are chosen, in one of which an excess of one, in the other an excess of the other ether is being liberated, and they are moved upon one another, some of the two ethers found, from time to time, disentangled from one another (see p. 67) at the surfaces in contact, will be drawn in opposite directions, and will not immediately re-intermix, as under ordinary circumstances they would do.

And we conclude that as the ethers, thus from time to time disentangled, flow in opposite directions across the surface separating the moving bodies, in obedience to the law of opposite currents above established, the direction which each ether takes, *i.e.*, which of the two exciting substances it passes towards, will ultimately depend on the relative proportions of the two ethers which the two substances are respectively emitting.

Since, as we saw just now, any excess of one ether present at any time around the molecules of a body ordinarily, *i.e.*, unless the body is very perfectly insulated, passes more or less readily away by conduction, and the proportion of the two unmolecular ethers ordinarily present anywhere, is, consequently, that in which they would symmetrically intermix, we conclude that, so far

comes out conspicuously hereafter, when we deal with continuous currents of electricity (p. 126).

The velocity of the two ethers in opposite directions will evidently depend on the velocity with which the intermixing ethers pass into each other ; it appears to vary according to circumstances.

as the liberation of electricity by friction depends on the disentanglement from each other of the intermixed unimolecular ethers adherent to the molecules of the electric, and not directly on atom destruction occurring at the time, the quantity of positive ether separated in one direction will bear a constant ratio to the quantity of negative ether separated in the opposite direction, *i.e.*, the ratio of the quantities necessary to produce a symmetrical intermixture, and the fact that all experimenters are agreed that *equal quantities* of positive and negative electricity are developed in cases of the frictional generation of electricity, as well as in other cases to which reference will be made subsequently, goes therefore to show that it is not to the destruction by the friction of the atoms of the electric that the presence of unmixed ethers, or electricity, is chiefly due, but to the separation of the mixed unimolecular ethers present, in the manner described.

Bearing on this, we have the experimental conclusions of Peclet, that the quantity of electricity generated is independent of the pressure, and of the breadth of the rubber, measured perpendicular to the axis of rotation, and that it varies as the angular velocity of the cylinder, and even that it is the same for rolling friction as for sliding friction, if the material of the rubber remains unchanged.

It is instructive, in this connection, to notice that the same body may, under different conditions of friction or temperature, furnish now one, now the other, kind of electricity. Thus, Canton, in the last century, discovered that, having roughened a glass tube by grinding its surface with emery and sheet lead, it possessed vitreous or positive electricity when rubbed with oiled silk, but resinous or negative electricity when rubbed with new flannel. He found, in short, that positive or negative electricity might, in certain cases, be developed at will

in the same tube, by altering the surfaces of the tube and the exciting rubber. Further, removing the polish from one half of the tube only, he excited the different electricities with the same rubber at a single stroke, and, curiously enough, the rubber was found to move much more easily over the rough than over the polished half.*

Canton likewise discovered that glass, amber, sealing wax, and calcareous spar were all electrified positively when taken out of mercury; and hence he was led to the important practical discovery that an amalgam of mercury and tin applied to the surface of the rubber was most efficacious in producing electricity in conjunction with glass.†

Professor Guthrie has recently called attention to the interesting fact, that while, when flannel is rubbed with ebonite it is positively electrified, and when ebonite is rubbed with glass it is positively electrified, when flannel is rubbed with glass the flannel becomes feebly negative.

Glass discs in electrical machines appear to be generally improved by age and use.

The consideration of the principle of the electrical machines which act by induction is deferred (see p. 97).

Leaving the further consideration of electrical conduction till we deal with the subject of electric currents, we will pass on to consider in the next chapter the subject of statical electrification.

* This appears to be an interesting exhibition of our fundamental property, cohesion.

† "Ency. Brit.," Art. "Electricity," p. 7.



CHAPTER VIII.

ELECTROSTATICS.

Attraction and Repulsion.

AMONG the phenomena by which the presence of electricity is ordinarily manifested, *attraction* and *repulsion* hold the most prominent place.

We all know that when a body is electrified statically by friction, or by other means, it has an attraction for other unelectrified, or oppositely electrified bodies, and that it also has a repulsion for bodies which are similarly electrified ; this being shown in the simplest manner by the electric pendulum, which consists of a pith ball suspended by a silk fibre from an insulated support.

Thus, when an electrified glass tube is brought near the pith ball, the latter is attracted ; but as soon as it touches the glass tube, the attraction is changed to repulsion, which lasts as long as the ball retains the electricity which it has acquired by the contact. A similar experiment can be shown, employing, instead of the glass tube, any other body which has been electrified by friction ; for example, a piece of resin, which has been rubbed with flannel. And if, while the pendulum exhibits repulsion for the glass, the electrified resin is brought near it, it is attracted ; and conversely, when it is repelled by the resin, it is attracted by the glass, making it clear that the electricity developed on the resin is not of the same kind as that developed on the glass, since the electrified resin and the electrified glass

exhibit opposite forces towards any third electrified body, each attracting what the other repels.

The electricity which glass acquires when rubbed with silk is what is called *positive*, or sometimes *vitreous*, electricity; and that which resin acquires by friction with flannel is what is called *negative*, or sometimes *resinous*, electricity.*

Further, the force of attraction exercised by electrified bodies on bodies which are unelectrified, or oppositely electrified, has been found, like the force of gravitation, to obey the law of inverse squares as to the relation between the intensity of the force and the distance between the bodies.† Thus, if l be the distance between the centres of two spheres, not in contact, one of which is electrified and the other unelectrified, and F the force of attraction subsisting between them, then F varies as $\frac{1}{l^2}$, and, if we allow that the attraction exercised by the quantity of electricity present in a conductor varies as this quantity, we have the force between two points, distant l , acting in the straight line which joins them and $= \frac{qq'}{l^2}$, where q, q' are respectively the quantities of electricity collected at the two points, and the units being properly chosen.

Like the force of gravitation, the force of electrical attraction has never hitherto been satisfactorily explained. A theory of gravitation has already been propounded in this treatise (see p. 39), and theories will now be submitted to account for electrical attraction and repulsion.

The theory of electrical attraction we have to offer is as follows :—

According to the theory above given of what constitutes electrification, an electrified conductor contains an appre-

* See Note †, foot of p. 64.

† This has been approximately determined by Coulomb's torsion balance, to which reference will be made presently.

cialle excess of one ether present alone, unmixed with the other ether, in the mass of unimolecular ethers found among its molecules.

Further, we conclude that this unmixed ether, which forms the electric charge, in obedience to the law of symmetrical intermixture, at its confines intermixes with, and consequently moves towards, any small masses of the other ether found unmixed in contact with it (see p. 9), and that in the process portions of the ether which do not immediately intermix are drawn along by portions which do, as above explained (see p. 75).

If a charged conductor is surrounded on all sides by non-conducting bodies, since the continuity of any unmixed ethers found in bodies of this nature is, as we have supposed, continually broken by motions of the non-conducting matter, *the passing outwards of the ether of the charge occurring as just stated, will take place but slowly, portions of this ether from time to time gradually filtering into and through the surrounding medium, and in this way achieving a slow, sometimes imperceptible, but practically continuous radiation in every direction.* And the slow motion outwards of portions of the ether of the charge will be accompanied by a slow motion in the opposite direction of the other ether, as the result of the action of the law of symmetrical intermixture just now referred to (see p. 75).

Now, when an electrified body and an unelectrified, or oppositely electrified, body are placed in proximity, we suppose that the radiation of the ether in excess from the former, which we have thus concluded is slowly taking place, *encounters less resistance, and is, consequently, greater on that side of it which is nearest to the latter,* ether movement being facilitated by the presence of the conducting body; and, if this is so, we have also at the same place a stronger movement of the other ether in the opposite direction.

That this will account for the attraction observed we argue as follows :—

The adhesion or cohesion between the molecular surfaces in the interior of bodies, and the unimolecular ethers in contact with these surfaces will, it is evident, cause a molecular body whose contained ethers are moving more in some directions than in others, to suffer displacement in the direction of the resultant of the various motions of both kinds of ethers (any difference in the amount of adhesion of the two ethers to the molecular surfaces being taken into account).

And, therefore, if, as just supposed, the ether radiation from an electrified body placed in proximity to an un-electrified or oppositely electrified body is greater in the direction of such body than in other directions, the electrified body will be drawn in this direction ; and if, further, the movement of the other ether from the un-electrified, or oppositely electrified body towards the electrified body is also stronger at the same place, this body will similarly be drawn in the direction of the electrified body ; in other words, the two bodies will be drawn or attracted towards one another.

That the attraction is greater in the case of an oppositely electrified body than in that of an unelectrified body, may, it is evident, be attributed to the radiation produced from the latter being feebler than that produced from the former, and also to the radiation of one kind of ether from the unelectrified body towards the electrified body being necessarily accompanied by a radiation of a corresponding amount of the other ether from the unelectrified body in other directions, the effect of the latter in imparting motion to the unelectrified body in other directions, to a great extent neutralizing the effect of the radiation towards the electrified body.

We have some elucidation of the fact of the force of

electrical attraction approximately obeying the law of inverse squares, in the familiar property that the amount of radiation from a body which is intercepted by another given body some distance from it, practically varies as the inverse square of the distance, if we suppose that the radiation occurs uniformly in straight lines, which, if produced, would intersect at the centre of the radiating body, and that the second body is always so placed with respect to the first that a straight line joining the centres of the two bodies always passes through the same point on the second body.

For this to explain the existence of the law under consideration, it appears, however, to be necessary to suppose that the ether radiation occurs with practically the same degree of facility, irrespective of the distance between the bodies, and that the radiation occurring in other directions than that of the second body, is so much weaker than the radiation towards this body as to be negligible.

The theory which we have to offer of the repulsion observed when two similarly electrified bodies are placed in proximity, is as follows:—

Since, when bodies are similarly electrified they contain the same kind of ether in excess of the other ether, two similarly electrified bodies radiate the same kind of ether, and, as the radiation depends, according to the above, on the presence in the surrounding non-conducting medium of the other kind of ether to intermix with the unmixed ether of the charge, it is evident that when the two bodies are in proximity, there will, in the case of each, be less radiation on the side turned towards the other body.

Now, since in both conducting bodies the ether in excess preserves far more continuity than the other ether does, we conclude that the molecular matter of both will partake more fully of the various motions of the ether in excess, than of those of the other ether.

Consequently, we attribute the moving apart of the two bodies to the drag, in opposite directions, on their intermolecular surfaces (p. 40) of the moving ether of the charge, as this ether radiates into space from their remoter sides more freely than from the sides which are turned towards one another.*

Examples of electric repulsion are very numerous, and need not be given here. There is, however, a simple experiment which appears to afford an instance of ether radiation extending the conducting body from which it is taking place.

A trough of mercury is divided longitudinally by a non-conducting partition. A varnished wire is bent into such a form that the two extremities of it can respectively float upon the two surfaces into which the mercury is divided, the central portion of the wire forming an arch over the partition. The only portions without varnish are the ends. When the terminals of an electric battery are inserted in the mercury, both at the same end of the trough, one in each division, the circuit is completed through the arched wire, and we evidently have a circuit of variable length, according to the position of the connecting arch of wire which spans the partition. It is found that when the current passes, the wire retreats from the terminals, making the circuit as long as possible.†

It may be objected to the above theories, both to that of

* Instances of motion imparted to a body through the radiation of some fluid material from it, are, we may remark, familiar to us. We have plenty of examples of motion obtained in this way, in the propulsion of fireworks, through the sudden liberation of rarefied and exploding gases. And we may also mention the movement produced by the emission of steam from an orifice.

An example of movement, which we should refer to ether emission, is presented by what are called electric whirls, to which reference is made presently (Note *, p. 109).

† Deschanel's "Electricity," translated by Prof. Everett, p. 681.

electrical attraction, and to that of electrical repulsion, that the action of a charged conductor is ascribed to a radiation of the ether, that if this occurs it must gradually draw away the excess of one ether, to which the electrical condition has been ascribed, and that we should have a continually falling potential, and sooner or later find the charge entirely dissipated, and that this appears inconsistent with fact. For, although under ordinary conditions, electrical charges in insulated conductors are speedily dissipated, this would seem to be due to moisture in the air or on the surface of the insulating support, and more and more stable electrification is displayed as insulation in vacuo is perfected, two sheets of gold leaf, electrically repelling each other, having been known to remain at sensibly the same angle of separation for months together.*

Perhaps this objection is adequately met by the supposition that the very small waste of the unmixed ether of the charge, which our theory requires us to suppose is occurring in such a case, is completely made good by *an excess of this kind of ether* set free by molecule destruction continually proceeding in the gold, as in all other bodies (see p. 21).

The foregoing theory, that it is the radiation of the ethers which produces attraction, receives important corroboration in the sequel, in a reference to some recent experiments by Prof. W. Holtz (see p. 100).

Other manifestations of the presence of electricity, such as combustion, incandescence, phosphorescence, explosion, etc., will be found referred to in the sequel.

* In ultra gas, a pair of electrified gold leaves have remained repelled, at absolutely the same angle, for thirteen months. Proc. R. S., No. 193, 1879, p. 347.

CHAPTER IX.

ELECTROSTATICS.—*Continued.**Insulation—Electrical “Density” and Distribution.*

ACCORDING to the above, as well as according to experience, the presence of an electric force does not necessarily involve an electric current; the existence of the bodies known as non-conductors, to which reference has already been made, permitting us to conceive of a space, or electric field, in which an excess of one ether* is present unmixed with the other, but from which, owing to its being completely enclosed by non-conductors, no continuous current is passing.

It is evident that equilibrium in such a field is attained when the ether present in excess is so distributed that no ether current exists within the field; the case being then parallel to the case of water which has found its level in some receptacle.

We express in the language ordinarily employed the fact that an electric field tends to this condition of equilibrium when we say that all points *within* the field are found to be at the same electric potential.

As to the nature of the distribution of the unmixed ether, within such a field, when there is equilibrium:—

* Excess of one ether means, in all cases, the amount of one ether over and above the relative quantities of the two which neutralize each other, apart from the question whether such neutralization is effected by *equal* quantities of the two ethers, or otherwise.

To take the simplest form for such a field. Suppose we have a sphere of metal, or of other conducting material, as the body throughout which the ether shall be free to circulate; or, in other words, as marking the shape of the electric field; and that it is supported on a stem of glass, or other non-conductor, so as to be completely enclosed by two non-conductors, air and glass.

Now, according to our theories, a large part (subsequent considerations will lead us to believe, by far the chief part) of the unimolecular ethers present among the molecules composing the molecular mass, consists of the two ethers satisfying each other, *i.e.*, in a state of mutual symmetrical intermixture, and only the small excess of *unmixed* ether present is concerned in producing electrical phenomena.

A clue to the distribution of this excess will, we should expect, be given by the electrical phenomena it produces, and, as a matter of fact, we have the following very remarkable, well-known phenomenon.

If the insulated sphere we employ is hollow, with an orifice in the top, when a *proof-plane*, as it is called, consisting of a small disc of gilt paper insulated by a thin handle of shellac, is applied *first* to the *interior surface* of the sphere, and, tested by an electric pendulum, or an electroscope,* it is found to exhibit no trace of electricity. But, when next it is applied to the *external surface* of the sphere, it is found to be electrified, and capable of attracting light bodies.†

* The ordinary gold leaf electroscope, for detecting the presence of electricity, and determining its kind, depends merely upon the principle of electrical repulsion of bodies similarly electrified. The instrument known as Coulomb's torsion balance was invented by the investigator of that name to measure *quantity* of electricity. It is not necessary to particularly describe its construction here, as a description will be found in most electrical treatises; but it may be stated that it depends on the principle that the torsion of a wire is simply proportional to the twisting couple.

† Deschanel's "Electricity," translated by Prof. Everett, p. 524.

We naturally conclude that the unmixed ether carried off by a proof-plane is simply that which was residing on the part of the surface covered by the proof-plane before its application, the latter being virtually part of the surface of the conductor during the time of its contact.

The most striking experiment ever made, demonstrating the above-mentioned fact, is that described by Faraday, in his "Experimental Researches." He constructed a hollow cube (12 feet in the edge) of conducting matter, and insulated it in the lecture room of the Royal Institution, and he tells us, "I put a delicate gold leaf electrometer within the cube, and then charged the whole, by an outside communication, very strongly for some time together; but, neither during the charge or after the discharge did the electrometer, or the air within, show the least sign of electricity. . . . I went into the cube and lived in it, and using all other tests of electrical states, I could not find the least influence upon them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every point of its outer surface."

We conclude, therefore, that, in the case referred to, the ether which is in excess, and which, according as it is the more readily compressible or the less readily compressible ether determines whether the electrification shall be positive or negative, is found entirely, or almost entirely, at the outer surface, and not within the body of the conductor. And, generally, it would appear that in all cases where one of the two ethers constituting the unimolecular ethers present among the molecular matter of a body is in excess of the other, the unmixed portion thus in excess passes to the outer boundary of the body, leaving the intermixed ethers, which neutralize each other electrically, in possession of all the interior space allotted to unimolecular ethers.*

* An apparent exception to the above-stated law occurs when an

The explanation of this, which suggests itself, is that the particles of unmixed ether, which are continually radiating from the surface of the body on all sides, by their motions produce currents of the remaining particles of the same unmixed ether which, setting from the centre to the circumference of the conductor, draw this unmixed ether to the circumference.

Next, as to the nature of the distribution of the unmixed ether of the charge at the surfaces of bodies:—

Coulomb has made several experimental investigations as to electrical distribution, the course pursued being as follows:—He touched the electrified body at a known point with the proof-plane, and then ascertained with the torsion balance the amount of torsion requisite to resist the repulsion exercised by the proof-plane thus electrified upon a brass ball charged with the same kind of electricity. He then repeated the process with electricity taken from a different point of the body under examination, and the ratio of the electrical "density" at the two points was given by the ratio of the torsions.

It is found that when the proof-plane is applied to different parts of the surface of a conductor the quantities of electricity which it carries off are not usually equal, from which we conclude that equal areas on different parts of the surface of a conductor do not contain equal quantities of the unmixed ether.

It is also found that if the charge of the conductor be varied, the quantity of electricity resident upon any specified portion of the surface is changed in the same ratio.

electrified body is enclosed within, but insulated from, a hollow conductor, the laws of induction, to which reference will hereafter be made, in this case disturbing the conditions under which electrification is ordinarily confined to the surface of a conductor.

And in the case of continuous electric currents, we commonly find evidence that the current traverses the interior as well as the surface of the conductor which carries it.

The ratio of the quantities of electricity at two specified portions of the surface is in fact independent of the charge, and depends only on the form of the conductor.

These facts are usually expressed by saying that *distribution* is independent of charge, and that the distribution of electricity on the surface of a conductor depends on its form.

The following are some of the results obtained by Coulomb :—

1. In the case of a *sphere*, the electrical “density” per unit of area is the same for all points on the surface.

2. *Ellipsoid*. The electrical “density” per unit of area is greatest at the ends of the longest, and least at the ends of the shortest, axis ; and the “densities” per unit of area at these points are simply proportional to the axes themselves.

3. *Flat disc*. The electrical “density” is almost inappreciable over the whole of both faces, except close to the edges, where it increases almost *per saltum*.

4. *Cylinder with hemispherical ends*. The electrical “density” per unit of area is a minimum and nearly uniform, at parts remote from the ends, and attains a maximum at the ends. The ratio of the electrical “density” at the ends to that at the sides increases as the radius of the cylinder diminishes, the length of the cylinder remaining the same.

5. *Spheres in contact*. In the case of equal spheres, the charge which is nothing at the point of contact, and very feeble up to 30° from that point, increases very rapidly from 30° to 60° , less rapidly from 60° to 90° , and almost insensibly from 90° to 180° . When the spheres are of unequal size, the charge at any point on the smaller sphere is greater than at the corresponding point on the longer one, and as the smaller sphere is continually diminished, the other remaining the same, the ratio of the “densities”

per unit of area at the extremities of the line of centres appeared to tend to the ratio 2 : 1.*

According to our theories it is relative quantity of the excess of unmixed ether present at different parts of the surfaces of bodies of different form which is determined in these experiments, and our explanation of the remarkable distribution of this ether which is revealed is as follows :—

We have concluded that the gentle radiation of the unmixed ether of the charge which proceeds from the surface of the electrified body draws all this unmixed ether away from the centre to the circumference of the body. When the radiation is uniform it is evident this ether will be drawn towards every part of the circumference equally, but when the radiation is greater at some places than others, the ether movement will be greater towards the places where there is greater radiation.

Now the ether radiation will evidently proceed with greater facility where the surface is more convex and least sheltered by any neighbouring prominences, which are themselves radiating the same ether; and at sharp projections, such as the points or edges of a body, its relative facility will be very great indeed.

Therefore the more convex a portion of surface relatively to other portions of the same surface, and the less sheltered by any of these other portions, the more the unmixed ether will be drawn to it, and consequently the greater the proportion of this ether which will be found there.

* Deschanel's "Electricity," translated by Prof. Everett, p. 529.

CHAPTER X.

ELECTROSTATICS.—*Continued.**Electrical Induction—Electric Shadows.*

THE next phenomenon which claims our attention is that of *Electrical Induction*.

It is commonly shown by means of the apparatus represented in Fig. 2,* which consists of a sphere *c*, and a

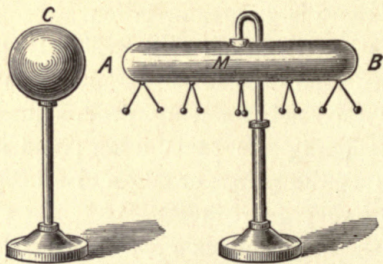


Fig. 2.

conducting insulated cylinder *AB*, from which are suspended at equal distances a few pairs of pith balls.

The sphere is charged with electricity, but not the cylinder ; and it is then found that if the electrified sphere is brought near to one end (*A*) of the cylinder, electrification of the latter, due to the proximity of the former, is evidenced by the divergence of the pairs of balls. The divergence of the different pairs is not however the same, but is less in successive cases from the pair nearest the

* This is taken from Deschanel's "Electricity," edited by Prof. Everett, p. 513.

sphere until a point *M* is reached, where there is no divergence. Beyond this successive pairs of balls exhibit increased divergence. The neutral point *M* does not exactly bisect the length of the cylinder, but is nearer the end *A* than the end *B*, and the former end is found to be more strongly electrified than the latter. The two ends of the cylinder are found to be charged with opposite kinds of electricity; the end *A* being charged with the different electricity from that in the sphere *C*, and the end *B* with the same electricity as that in the sphere *C*. If the cylinder be brought closer to the sphere the divergence of the balls increases; if it be removed farther from it, the divergence diminishes. All signs of electricity disappear if the sphere be taken away, or connected with the earth.

If, while the cylinder is under the influence of the electricity of *C*, the end *B* is connected with the earth, the pith balls at this end immediately collapse, while the divergence of those at *A* increases, and we find that the whole of the cylinder is now electrified with the opposite electricity to that in *C*, the neutral line being pushed back to the earth.

If the earth connection be now broken, and the sphere *C* be then removed, the cylinder will remain electrified just as though it had been touched by an electrified body. This mode of giving a charge to a conductor is called *charging by induction*, and the sign of the charge thus given is always opposite to that of the inducing charge in *C*.

If a series of conductors similar to *AB* be placed in line, without contact, and the electrified body *C* be placed opposite to one end of the series, all the conductors will be affected in the same manner as the single conductor; they will each be charged with the opposite electricity to that in *C* at the end nearest *C*, and with the same electricity as that in *C* at the remote end, the effect, however, becoming feebler as we advance along the series.

The explanation of these phenomena which is here offered is as follows :—

Suppose that the unmixed ether in excess present in the sphere C is positive ether,—*i.e.*, of the kind which produces positive electrification.

Particles of this ether are, according to the conclusions we have reached, radiating from the electrified sphere towards the end A of the cylinder, and producing a radiation from the cylinder of negative ether in the opposite direction.

The radiation of negative ether from the cylinder thus set up, we may suppose, from the arguments of the preceding chapter, creates a flow which draws out negative ether from the intermixed mass of unimolecular ethers present in the cylinder, and accumulates it so as to form a sort of cap of this ether at the surface at the end nearest to C, the maximum depth or “density” being found at A.

Since the unimolecular ethers of the conductor AB are at first all intermixed, the separation of negative ether arising in this way involves the separation of an equal quantity of positive ether ; and as the latter will evidently find the most unimpeded radiation at the end of the cylinder furthest from C, it will similarly accumulate so as to form a sort of cap of positive ether at this end, with a maximum depth or “density” at B.

This explanation is consistent with the fact that the larger the conductor AB, the greater the accumulation of negative electricity at A, the greatest accumulation taking place when by connection with earth this conductor is rendered “infinite.” For it is reasonable to expect that the radiation of the negative ether from the cylinder will be greater the greater the quantity of intermixed unimolecular ethers contained in one continuous conductor from which it is drawn, and the greater the radiation the greater the quantity of ethers separated.

We shall presently find experimental reasons for concluding that when the conductor A B is very large the quantity of negative ether separated and accumulated at the end A is just that which would suffice to intermix with so much of the positive ether in C as is radiating particles towards A B.

It is evident that the two conductors employed in the above experiment, or indeed any number of conductors similarly related, behave, so far as the electrical functions of the extremes of the system are concerned, just like a single, *continuous*, electrified conductor.

How completely a system of bodies, one of which contains an electric charge while the remainder are uncharged until acted upon by induction, thus behave like one single electrified conductor, is well shown by Faraday's experiment with the ice-pails.*

Let A (Fig. 3) represent, in section, an insulated pewter ice-pail, ten and a half inches high, and seven inches in diameter, connected by a wire with a delicate gold leaf

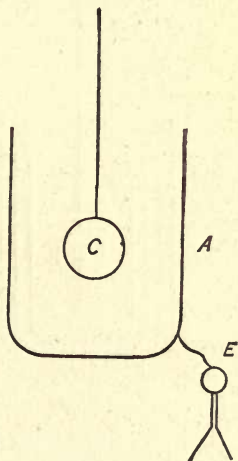


Fig. 3.

electroscope E, and let C be a round brass ball, insulated by a dry thread of white silk, three or four feet in length, so as to remove the influence of the hand holding it from the pail below. Let A be perfectly discharged, and let C, after being charged at a distance, be introduced into A, as in the figure. If C be positive, E also will diverge positively; if C be taken away, E will collapse perfectly, the apparatus being in good order. As C enters

* The description of this experiment is taken from Deschanel's "Electricity," translated by Professor Everett, p. 526.

the vessel A, the divergence of E will increase until c is about three inches below the edge of the vessel, and will remain quite steady and unchanged for any greater depression. If c be made to touch the bottom A, all (that is, practically all) its charge is communicated to A, and c, upon being withdrawn and examined, is found perfectly discharged.

Faraday found that at the moment of contact of c with the bottom A, not the slightest change took place in the divergence of the gold leaves. Hence, the charge previously developed by induction on the outside of A must have been precisely equal to that acquired by the contact. And we, therefore, conclude that the quantity of negative ether accumulated on the inside of the pail, in the way explained, is, practically, just what would suffice to intermix symmetrically with the positive ether constituting the charge on c.

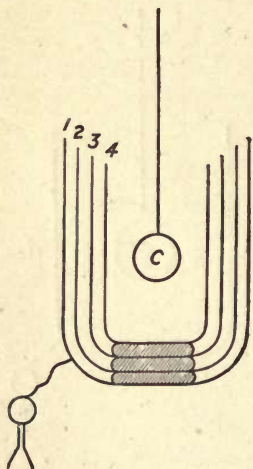


Fig. 4.

Extending the experiment, Faraday employed four ice-pails (Fig. 4), arranged one within another, insulated from one another by plates of

shellac at the bottom, the outermost pail being connected with the electroscope. When the charged carrier ball c was introduced within the innermost pail, and lowered until it touched the bottom, the electrometer gave precisely the same indications as when the outermost pail was employed alone. When the innermost was lifted out by a silk thread after being touched by c, the gold leaves collapsed perfectly. When it was introduced again, they opened out to the same extent as before. When 4 and 3 were connected by a wire let down between them by



a silk thread, the leaves remained unchanged, and so they still remained when 3 and 2 were connected, and finally when all four pails were connected.

The unchanged divergence of the electroscope, whether the conductors are insulated or in contact, indicates that the unmixed ether in excess has the same distribution at the extremes of the system, whether the system be electrically continuous or no. If the several conductors be insulated from each other, we conclude that there are in the intervening space alternate aggregations of the two kinds of unmixed ether of such quantity that they would just neutralize each other electrically if intermixed, the number of aggregations depending on the number of conductors employed. If the conductors be electrically continuous so as to form but one conductor, the only aggregations of this kind are those at the extremes of the system.

When two similarly electrified bodies are brought towards each other, it is often found that the repulsion, which is at first exhibited, changes to attraction, when a certain limit of distance is reached. The explanation, based on the above conclusions, which naturally suggests itself, is that a rearrangement of the unmixed ethers of such a nature that the sides of the two bodies nearest each other have different ethers upon them, is produced by near proximity of the bodies.

What is known as Holtz's machine may be referred to as furnishing an instructive example of electrical induction.

The mechanism of this machine consists essentially of two parallel discs of thin glass, placed close together, and one of which can be rapidly revolved. The stationary disc has two openings cut in it, upon the edges of which two sectors of paper are pasted, and so disposed that a blunt point of each piece projects beyond the edge to which it is

attached. Opposite the two blunt points of paper, and upon the opposite side of the rotating disc, the points of two metal combs are fixed projecting towards the discs, and close to the surface of the one in motion. Finally, these combs are respectively connected with the two ends of an insulated conductor, which is, however, capable of being divided into two conductors by the motion of a sliding bar.

To start the machine, one of the paper sectors is electrified from some external source, as, for instance, an excited sheet of vulcanite, and the movable disc set in rotation. Soon a powerful double flow of electricity is found to be taking place in the conductor which connects the two metal combs, a flow of positive electricity occurring in one direction, a corresponding flow of negative in the opposite direction, and if, when the current has become powerful, the contact in the conductor be broken, so that we have two conductors instead of one, brilliant discharges take place between them.

Following the line of argument laid down above, we suggest the following explanation of the action of a Holtz machine.

The unmixed ether imparted at starting to one of the paper sectors radiates particles through the revolving glass plate towards the metal comb placed opposite to this sector, and by the operation of the law of symmetrical intermixture, a corresponding radiation of the other kind of ether is therefore induced from this metal comb towards the electrified sector.

This latter radiation produces an accumulation of one ether in the metal comb, and consequently, as above explained, an accumulation of the other ether at the comb at the other extremity of the conductor.

Radiation of particles of this latter ether thereupon occurs towards the second paper sector, so that one ether

is being radiated from the comb at one end of the conductor towards one paper sector, the other from the comb at the other end of the conductor towards the other sector.

Finally (and this appears to be the important principle involved), when the disc is rotated the moving molecular mass, having cohesion with the ether particles which are passing out from the points of both combs simultaneously, drags out from the mass of intermixed unimolecular ethers present in the conductor an increased flow of the one kind of ether from one comb, and an increased flow of the other kind of ether from the other comb, and thus intensifies the double current in the conductor connecting the metal combs which is already existing, the rotating disc being meanwhile continually neutralized.

In support of the above explanation, it is interesting to notice that soon after it is started, the machine becomes sensibly harder to turn; and that, as we should expect, the direction of the current is independent of the direction of rotation, except in so far as a given direction of current tends to be continued. This independence of the direction of rotation conspicuously appears in the interesting fact that a reversal of the direction of flow of the two electricities occurs if we use a condenser of considerable capacity in connection with the conductor, and separate the two portions into which the conductor is divisible by a considerable interval, so that a discharge takes place along the surface of the disc, instead of between the two portions of the conductor; the direction of the electricities being reversed each time such a discharge occurs, and the conductor, which was positively electrified, becoming negatively electrified, the rotation meanwhile being continued in the same direction.

We have another example of induction in the simple apparatus called the *electrophorus*; as, however, the principle of this instrument is that of an electrical condenser, the

explanation of it is deferred until we deal with electrical condensers (see p. 115).

Electric Shadows.

A new class of electrical phenomena has been recently brought to light by the researches of Professor W. Holtz, of Berlin, which may appropriately be mentioned here. We refer to what their discoverer calls *Electric shadow-figures*. These phenomena afford some support to the theories of electric action which have been propounded. The following description is quoted from *Nature*, No. 606, p. 130 :—

“From the discharging-rods of a Holtz machine the brass balls are removed. To the left rod there is attached in place of the ball a circular disc of some 10 to 20 centimetres diameter, having its front face either flat or slightly concave. To the right rod a point is fixed, and it is drawn back till from 6 to 15 centimetres distant from the disc. A piece of silk or satin of the same size as the front surface of the disc is laid upon it while the machine is in action (it adheres of itself to the surface), and the preparation is now complete.

“Before the silk is placed over the disc a small ‘brush’ discharge of blueish light is all that can be distinguished at the point of the right hand discharging rod ; but this now changes to a very faintly glowing star. At the same moment the central region of the silk-covered disc exhibits a peculiar glimmering light over a well-defined circle. The utmost care is needed to shut out all extraneous light from the room, otherwise the delicate appearances which follow cannot be seen. It is upon this circular patch of feeble light that the shadow-figures are thrown. Its pale gleam becomes more vivid when the machine is more energetically worked ; it enlarges in area but diminishes in brightness as the point is drawn back from it, and

contracts with an accompanying increase of brightness as the point is brought nearer. It is possible to obtain a similar glimmering surface also upon a large metal ball covered with silk and attached to the rod in place of the concave disc, or instead a screen made of two or three folds of silk stretched over an ebonite ring may be placed between the two discharging rods, the ends of both being furnished with points. In each case it is important that the silk be without crease or wrinkle, otherwise an evenly illuminated disc of light will not be obtained.

“If now a body of definite outline of form be interposed between the point and the disc, an electrical shadow of it will be cast upon the luminous circle. These shadows are truly electrical, not optical, for all bodies do not cast them, and, more curious still, different bodies, though of the same shape, may cast differently shaped shadows. Conductors of electricity cast well-defined shadows, and so do semi-conductors, such as wood and cardboard. True insulators of small dimensions cast no shadows. The insulation or non-insulation of the conducting bodies makes no difference in their shadow-giving power. A cross cut out of cardboard casts a well-defined shadow at the centre of the field, but the exterior portions are somewhat hazy.”

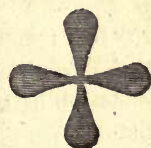


Fig. 5.

(To give an idea of the curious modification in shape which a plain cross undergoes in its shadow see Fig. 5.)

“An ebonite cross casts no shadow. A cross made of two strips, one of cardboard, the other of ebonite, fastened with shellac, casts only a single bar of shadow. Rings of tinfoil, cardboard, or wire also cast shadows. Such small objects are conveniently held by attaching them to the end of glass rods. The size of the shadows increases if the objects are displaced from their central position to right or left. A

strip of card or thin metal casts the same shadow whether it be held broadside or edgeways in the field. A wire grating having five millimetres width between the bars obscures the field like an opaque body. Breathing on a strip of ebonite or glass renders its surface a feeble conductor, and it casts a transient shadow. A glass rod heated at one point casts a shadow at the heated point, the shadow dying out as the rod cools. No shadow is cast by a conductor whose surface is completely covered by insulating material, such as a shellac-covered wire, or a glass tube containing water, but dry externally. The smoke ascending from a cigar casts moving shadows upon the silken screen. If a small ball be fixed upon the left discharging-rod in place of the point, the shadow on the silk is poor, but a second shadow is observed upon the surface of the ball ; and this is excessively small, reminding one of the diminished, erect, virtual, optical image in a small polished ball. This one experiment succeeds best if the ball be made the positive conductor. For the other experiments it makes little difference whether the electrification of the point be positive or negative, except that when the point is positively electrified the illuminated surface is a little larger than when negatively electrified. A larger disc of light can also be obtained by working the machine at a greater velocity, but at the same time the shadows are rather smaller. . . . The same kind of phenomena have been investigated in America by Messrs. Fine and Magie. They added the interesting observation that the lines of electrical action were deflected by the presence of a conducting body at the side of the field, and the form of the shadow correspondingly altered."

Further, Prof. Augusto Righi, of Padua, in a recent memoir on the subject of electric shadows, observes that if the object giving an electric shadow is itself *electrified similarly* to the discharging point the shadow is extended,

while if it is *oppositely electrified* or connected with earth the shadow is attenuated.

Let us endeavour to explain these interesting phenomena :—

As to the luminosity of the silk-covered surface, a theory is submitted hereafter that light-producing ether waves originate in the concerted explosions of primary atoms (see p. 202), and accordingly we suppose that the luminosity observed is due to atom-explosion produced by the action of the moving ethers of the discharge on the molecular matter of the non-conducting silk interposed in its path.

Next with reference to the characteristic peculiarities of electric shadows, the existence of which evidently indicates the withdrawal or diversion of certain portions of the stream of particles of unmixed ether passing from the pointed conductor through the air-space.

According to the theories which have been submitted, the motion of positive ether in one direction, and of negative ether in the other through the air-space between the two conductors is to be attributed to the occurrence of symmetrical intermixture between the two differently compressible ethers, and therefore depends on each ether from time to time encountering the other. But we have supposed that continuous chains of particles of each ether unmixed with particles of the other are present in conducting bodies (p. 66), therefore it is natural further to suppose that in such bodies the radiation of particles of ether is here and there checked, as these particles encounter continuous patches of the similar ether.

Thus we account for the fact presented to us that conducting bodies form a barrier to ether radiation though not to ether conduction.

The fact observed, that an excess, in the object giving the shadow, of the same kind of ether as that radiating from the point extends the shadow, we shall, consistently

with this, attribute to the presence immediately around the object of the ether thus in excess. And, on the other hand, the fact that an excess in the object of the other ether attenuates the shadow, we shall attribute to the similar presence of this other ether inviting intermixture with the ether passing from the point, and thus facilitating radiation.

The paths of the radiated ether particles will evidently, according to our theory of ether radiation, depend on the form and extent of the conducting surface behind the silk screen. We suppose further that they are influenced by the occurrence of ether radiation from the object interposed, or from neighbouring objects, if such are present; the power the object interposed has of drawing towards it ether particles which have come from the conductor, depending, accordingly, on its bulk rather than on the profile of it which is turned towards the radiating point.

CHAPTER XI.

ELECTRO-DYNAMICS.

*Ether Currents of Short Duration—Electric Condensers—
Effects of the Presence of the Unmixed Ethers on
Molecular Matter.*

WE have supposed electric conduction to be the result of a flow of unmixed ether, very analogous to the flow of a liquid (p. 65). According to this view, *time* must be an important element with regard to a flow of electricity in a conductor; for it is evident that, if the ether does not traverse a closed curve, the flow must be treated as of finite duration, and its effects must be looked for during a finite, and commonly a very limited period. We have, therefore, the important distinction between the electrostatical phenomena we have been considering, and the electro-dynamical phenomena we are now to consider; that while the former, which we have supposed to be due to motions of inconsiderable quantities of unmixed ether occurring from the surfaces of electrified bodies—the ethers percolating through the non-conducting media surrounding these bodies—*may be regarded as practically constant during the subsistence of given constant external conditions*; the latter, consisting of electric flows or currents in conductors—including in this definition all instances which can be attributed to the overflow or displacement of a body of dense unmixed ether of either kind caused by the pressure *directly applied* of another body of the same ether—*last only during the period the difference of ether pressure which*

causes them continues, which unless the ether traverses a closed curve, or the supply of unmixed ethers is very large indeed, must evidently be a very limited period.*

As appearing to be instances of ether flows or currents of short duration and unequal quantity during their continuance, we may mention the different forms of what is known as *the disruptive discharge*.

This occurs when the electric potential of an insulated conductor is sufficiently raised. We have its most familiar form in the electric sparks which pass from an excited electric, or from the conductor of an electrical machine, or between its various insulated parts. It is generally accompanied by sound, heat, light, or mechanical effects ; commonly by all these at once.

The various forms it takes will be referred to presently. The following explanation of its origin is suggested :—

When offering a theory of the phenomena of statical electrification (p. 81), we concluded that an electrified insulated conductor has an excess of one ether upon it, and that this unmixed ether gradually filters through the surrounding medium, encountering least resistance on the side nearest to any other conductor which will supply the other kind of ether for intermixture with the ether thus given off ; the unmixed ether of the change not passing away by conduction, because of the continual rupture of continuity of the portion of it which is penetrating the non-conducting medium, caused by the motions taking place in this medium.

Now, if this be so, we may conclude that increase in quantity of the electricity on the electrified conductor is just increase in quantity of the one ether which constitutes the charge, and that this produces increase in the quantity of ether filtering through the non-conducting medium, as

* Cases in which we conclude that the ethers traverse closed curves are considered subsequently.

shown by the increased electrostatic action, and which increase will, it is evident, be accompanied by a growing independence of the moving ethers of the nature of the non-conducting medium they are traversing, and a consequent lessening of the discontinuity which characterizes them in passing through this medium. *And thus, if the charge is sufficiently increased, we shall at last between the two conductors, in the line of strongest inductive action, have a continuous thread of particles of the same ether stretching from one conductor to the other, which thread of one ether will, according to the theory of conduction which has been propounded, itself constitute an electrical conductor.*

We suppose disruptive electrical discharge to be a rush of unmixed ether along the channel thus opened, occurring, much as a rush of pent-up water will do, soon after a small vent has been opened through a dam composed of displaceable material.

A fact which accords with the state of things we have thus supposed to be immediately antecedent to the occurrence of the discharge, and which reveals a preparedness of the ether condition of the path along which the discharge is about to occur, is that sparks show a tendency to persist in a path once opened; indeed it has been recently shown that if electric discharges between the same points occurring at successive instants of time be compared, irregularities and peculiarities present in one of the series are found accurately repeated in other discharges in the same series.*

The fact that the nature of the discharge is regulated by the shape of the terminals between which it occurs, and by the nature of the non-conductor through which it passes, is also in harmony with our theory. A reference to the various kinds of disruptive discharge will illustrate this:—

The sparks furnished by powerful electrical machines, which are sometimes a foot in length, have usually a

* Lecture by Dr. W. Spottiswoode, at Royal Institution.

zig-zag form like flashes of forked lightning, and very frequently finer ramifications branch out from the main track.

The luminous appearances, called *brush discharges*, are produced when a powerful machine is working in a very dry atmosphere, and are the result of discharge radiated into the air; they may be rendered very conspicuous by presenting a large conducting surface at a distance a little too great for a spark to pass. The shape of this kind of discharge may be roughly compared to that of a Turk's-head broom; positive electricity gives larger and finer brushes than negative.

The explanation of this form of discharge which naturally suggests itself is that many continuous threads of particles of the ether of the charge, such as we have above referred to, are simultaneously produced between the discharger of the machine and the large conducting surface.

When discharge takes place from the rounded end of a wire projecting freely into the air, the brush is often replaced by a quiet phosphorescent glow, which covers a greater or lesser extent of the end of the wire. The noise which accompanies the brush discharge is entirely absent in this case. A discharge of this kind is invariably associated with a current of air to or from (generally both) the glowing conductor,* and Faraday has concluded that it proceeds gradually by convection. It seems pretty clear that it is a variety of the kind of discharge mentioned next.

Another form of electric discharge is that occurring from a point. If a metallic rod terminating in a point be attached to the conductor of the electrical machine, electricity escapes in large quantity from the point, which, when viewed in the dark, is seen to be crowned with a tuft

* "Enc. Brit.," Art. "Electricity."

of light. A continuous current of air is found to be proceeding from a point thus discharging.*

The great accumulation of electricity which occurs at the points or edges of an electrified body, we have referred to the greater facility of ether radiation which is afforded on prominences; we have only to suppose that the ether radiation is powerful enough to set up a current of the air particles among which it passes, and we appear to have an adequate source of electric convection. The smallness of the quantity of ether simultaneously given off accounts for the comparative insignificance of the luminous and other effects of this kind of discharge.

The remaining form of disruptive discharge, which it is proposed to refer to here, is the discharge in rarefied gases; it owes its distinctive character, not so much to the shape or nature of the terminals between which it occurs, although not uninfluenced by them, as to the nature of the non-conductor through which it passes.† In this kind of discharge there is, ordinarily, a dissimilarity between the luminous appearances of the positive and negative terminals; and in all instances, whatever the density of the gas, there is a tendency on the part of the luminosity to break up into disconnected blocks and, as gas of a less density is employed, to separate from the negative and cling to the positive terminal. Further, when the pressure is considerably reduced, these blocks are replaced by a beautiful system of flakes, or “*striæ*” of light, systematically arranged in concentric curves, or in

* This production of an air current is taken advantage of to produce rotation in the electric whirl.

† Reference has been already made to the degrees of resistance, or variations of conductivity, exhibited as we obtain different degrees of rarefaction of atmospheric air. It has been stated that the resistance is diminished by rarefaction up to a certain point, at which a reaction sets in, so that a very complete vacuum is a very excellent insulating medium.

regular layers, about the axis uniting the two terminals. As exhaustion proceeds the striæ become more and more separated, as well as individually thicker. At first mere flakes of light, they gradually increase in thickness until they assume the proportions of blocks of light, sometimes of larger dimensions in the direction of the axis of the

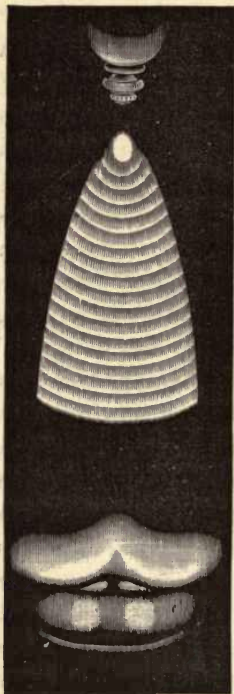


Fig. 6.

tube than in that of the diameter. At the same time the main dark space between the head of the column and a solitary luminosity about the negative terminal, as well as the dimensions of that luminosity itself, increase in length. A dark space immediately surrounding the negative terminal, and limited by the solitary stria, also begins to show itself, and to increase with the exhaustion. This space has been named after Mr. Crookes, who first made a study of it—"the Crookes' space." As we proceed yet further, the column retreats towards the positive terminal; and, at the last stage, the solitary luminosity shares the same fate, the Crookes' space occupies the whole tube, and no gaseous illumination whatever remains.*

The effect of using a small negative terminal is to greatly increase the resistance† to the passage of the discharge. If this terminal be large the discharge passes with comparative ease. With a small

* Taken from a lecture delivered before the British Association, at York in 1881, by William Spottiswoode, D.C.L., LL.D., President of the Royal Society.

† On Resistance, see p. 150.

negative terminal striæ are formed only with difficulty, if at all; with this terminal large they are readily formed.

Figure 6 gives an idea of the arrangement of the striæ, in the case of high rarefaction.

According to the theories that have been submitted, these very striking phenomena must be regarded as indicating some remarkable interaction between molecular matter and unimolecular ethers. It is suggested that they are probably due to symmetrical intermixture occurring between the tenuous molecular matter and the unimolecular ethers, and to the compounds thus formed being distributed in distinct patches between the terminals. And some explanation of how this may occur as a consequence of the supposed nature of molecular matter and of the unimolecular ethers will appear subsequently, when we come to deal with chemical combination (see p. 359).

That the appearances presented do indicate the distribution of the rarefied molecular matter in patches, is supported by some observations made by Yvon Zoch upon a new kind of electric dust-figures—Tubes of 1 to 3 centimètres diameter, and from 10 to 30 centimètres in length, were closed at both ends by corks, pierced to receive copper wires. In the tubes were placed various powders, bronze powder being chiefly used in preference to others, which, being lighter, adhered to the sides of the tube. One wire was then connected with the positive conductor of an electric machine, from the other the repelled electricity dissipated itself into the air. The experiments were all conducted at atmospheric pressure. When thus treated the bronze powder arranged itself in beautifully-marked ridges, or strata, varying in regularity, according to the original distribution of the powder. A space free from all traces of powder was observed to surround the positive pole. Usually there was a corresponding accumulation

about the negative pole. These ridges or striations were comparable to the stratifications observable in Geissler tubes ; and Herr Zoch shows that variations in the strength of the electric discharges, in the width of the tubes, etc., produce upon the figures similar effects to those they produce on the luminous striæ of vacuous tubes.*

The production of light of one colour by one rarefied gas, and of light of another colour by another,† and the falling off in splendour of the lights, both at the positive and negative poles, when the rarefaction is very extreme, are facts evidently in harmony with the theory we shall presently offer, that the waves which propagate light are produced by the concerted explosion of primary atoms (see p. 202).

Some reference is made, subsequently, to the electric discharges of thunderstorms.

Sir Wm. Thompson has found that the electromotive force,‡ or, as we should say, difference of ether pressure, required to produce a spark in air between two conductors, is disproportionately smaller for large distances than for small ; in other words, that the dielectric strength of a thin stratum of air is much greater than that of a thick one. Taken in connection with our conclusion, that the un-molecular ethers and the air molecules lying close to the free surface of a dense body are at a high density (see p. 50), the question asked by Prof. Clerk Maxwell, in reference to this fact, is interesting. He says, "Is it possible that the air very near to the surface of dense bodies is condensed so as to become a better insulator?"

* Taken from *Nature*, No. 583, p. 208.

† The reason why the colour of discharges in air at common density and temperature is practically white (it is slightly bluish), as compared with the light in vacuum discharges, is suggested hereafter, where also reference is made to the colours of discharges in gases. See chap. on Spectrum Analysis.

‡ For definition of this term, see p. 128.

With regard to limiting tension, Faraday came to the conclusion "that, when two equal small conducting surfaces, equally placed in air, are electrified, the one positively and the other negatively, that which is negative can discharge to the air at a tension a little lower than that required for the positive surface, and that, when discharge does take place, much more passes at each time from the positive than from the negative surface." This we should be disposed to attribute to the particular proportion of the two ethers being continually liberated in the insulating medium.

As we should expect from our conclusions, stated above—that the way is paved for disruptive charge by an increase of ether radiation through the insulating medium, and that radiation occurs with greater facility from more convex surfaces—disruptive discharge occurs more readily from some parts of a non-spherical conductor than from others; and thus, if it is desired to halve the charge between two equal conductors of similar form, it is found necessary that they shall be symmetrically presented to each other; suppose, for instance, they be ellipsoids of revolution, it will not do to make the pole of one touch the equator of the other.

With reference to the relative capacity for electricity of similar conductors of different sizes. Suppose that we have two similar insulated conductors of different size electrified so that the same electrical force is exerted by corresponding parts of their surfaces, in other words, so that the same electrical "density" prevails at corresponding points,* then, if corresponding points of the two conductors be simultaneously connected with earth, we may conclude from the equality of electric pressure that the initial velocity of the escaping unmixed ether will be

* This implies that the ethers are similarly distributed in the two similar conductors.

the same in the two cases, and, consequently, since corresponding lengths on the two conductors are as their linear dimensions, we may conclude that the times occupied in discharge, and the quantities of unmixed ether discharged, will both have the ratio of corresponding linear dimensions of the two conductors. Defining the electrical capacity of a conductor as the quantity of electricity required to charge it to unit potential, we obtain, therefore, the well-known general proposition that the capacities of similar conductors are as their linear dimensions.

This proposition is usually deduced from the law of inverse squares, but as we have up to this only traced the existence of this law for electrostatic action through insulating media, its use in such a way in these pages is evidently inadmissible.

Electrical Condensers.

As connected with the subject of disruptive discharges we will now offer a few remarks on what are known as *electrical condensers*.

Electrical condensers may be described in general terms as consisting of two conductors, having adjacent surfaces of considerable extent, separated by a thin stratum, or plate, of non-conducting material, generally called a dielectric, extending beyond the conductors. Thus, one of the first instruments of this kind was "Franklin's pane," which consisted of two sheets of tinfoil pasted opposite each other on the two sides of a pane of glass, the tinfoil not extending to the edges of the pane.

It is found that conductors thus arranged are capable of receiving a charge of electricity enormously greater than the charge which could ordinarily be imparted to them. One conductor only receives the charge, and the conductor which does not receive it is ordinarily connected

with the earth, and is found, in accordance with the principle of induction already referred to, to have an opposite electrification to that of the conductor to which the charge is imparted.

The most usual form of condenser, that known as the Leyden jar, is simply a modification of Franklin's pane, the glass jar taking the place of the pane of glass; the inner coating of tinfoil, which is carried uniformly to the same height as the outer coating, furnishing the one sheet of tinfoil, and the outer coating furnishing the opposite sheet; the cork, or stopper, which closes the mouth of the jar merely serves to keep out dust, and to carry a metal conductor connected with the inner coating.

Another simple instrument, which combines the functions of an electrical machine and an electrical condenser, is called the *electrophorus*. It consists of a disc of vulcanite, or of some other electric, and of a smooth metal plate fitted with an insulated handle. The vulcanite is electrified by flapping it with a catskin or flannel, and the metal plate then placed upon it; the latter does not receive a charge directly from the vulcanite, but if momentarily connected with the earth (say by touching it with the finger), and then lifted, it is found to contain an induced charge to a high potential of an opposite sign to that of the vulcanite, the charge being positive in the case supposed.

It is usual to fasten a base or *sole* of metal to the vulcanite, the advantage being that this has good earth contact, and being electrified by induction, strengthens the effect.

It is easy to see that the electrophorus is an electrical condenser of the nature above described, the air-space between the plate and the disc furnishing the dielectric through which the effect of induction is produced. The thinness of this dielectric is the cause of the amount of positive ether collected upon the face of the metal plate being almost

equal to the amount of negative ether upon the vulcanite.*

The large quantity of electricity which can be stored in a condenser, is evidenced when it is discharged by connecting, or nearly connecting its two conductors by means of some conducting body. The brilliant spark which can be produced in this way from a Leyden jar is familiar to everyone.

The theory of electrical condensers, which we have to offer, is as follows :—

When two conductors are separated by a dielectric, and one of them contains electricity, there is, according to the arguments submitted above, a radiation of particles of the unmixed ether which forms the charge across the dielectric towards the other conductor, and also a return radiation of the other kind of ether, so that positive ether is drawn into the dielectric on one side, negative ether on the other, both ethers moving but slowly through the dielectric, owing to

* A curious instance of electricity held in a body in the manner observed in electric condensers, was noticed by Symmer, about the year 1759. In pulling off his stockings in the evening, he had often remarked that they not only gave a crackling noise, but even emitted sparks in the dark. The electricity was most powerful when a silk and a worsted stocking had been worn on the same leg, and it was best exhibited by putting the hand between the leg and the stockings, and pulling them off together. The one stocking being then drawn out of the other, they appeared more or less inflated, and exhibited the attractions and repulsions of electrified bodies. Two white silk stockings, or two black ones, when put on the same leg and taken off, gave no electrical indications. When a black and a white stocking were put on the same leg, and after ten minutes taken off, they were so much inflated when pulled asunder, that each showed the entire shape of the leg, and at the distance of a foot and a half they rushed to meet each other. Further, if they were separated, and removed to a certain distance from each other, their electricity did not appear to have been impaired by the shock they had had in meeting; indeed, the experiment could be again and again repeated, till their electricity, gradually wasting, stood in need of being recruited. (Taken from "Enc. Brit.," Art. "Electricity," p. 7.)

the breaking of their continuity by the motions of the matter composing it, in the way already explained when we treated of non-conduction.

Now, it is evident that the shorter the distance the streams of ether have to traverse to pass from one conductor to the other, *i.e.*, the thinner the dielectric, the less will their continuity be broken by the molecular motions of the dielectric, and the more rapid will be their motion, and consequently the greater will be the quantities of unmixed ether drawn into the dielectric.

Again, where the density of the unimolecular ethers is less within the dielectric than within the conductors, we have concluded there will be a gradient of falling ether density from within the conductors across the surfaces separating them from the dielectric (see p. 50), and the thinner the dielectric the gentler this gradient will be, if, as just argued, the ether motions are more rapid.

Therefore, we conclude that in the case of a very thin dielectric, such as is employed in electric condensers, when an excess of one ether is imparted to one conductor there is a rapid passage into the dielectric of ethers at a high density, one ether from the one conductor, the other from the other, and that the moving ethers maintain a high density for some distance into the dielectric.

And finally, although the state of things just described evidently involves the passage between the conductors of much larger quantities of the unmixed ethers than when the conductors are more widely separated, we conclude that a considerable quantity of each ether is drawn into the dielectric, which does not filter much below the surface, and that, while the quantity of ethers passing, in either direction, the centre of the dielectric, at which the ether density is lowest,* is still comparatively small, a relatively

* That is, if, as supposed, the density of the unimolecular ethers is less within the dielectric than within the conductors.

considerable accumulation of the unmixed ethers takes place just within the dielectric, one ether penetrating a little below one surface, the other a little below the other.

Some important facts may be referred to in support of this theory of the condition of the dielectric of a charged electrical condenser.

Thus, that it is possible to charge a non-conducting substance with electricity has been well known for a long time, Canton having observed, in the last century, that the air in a room can be electrified positively or negatively, and that it will remain thus electrified for a considerable time.

Again, Franklin's experiment of the Leyden jar with movable coatings entirely confirms the conclusion that nearly all the charge, both of positive and of negative ether, is stored in the dielectric immediately beneath and upon its surface. The experiment is as follows:—A jar, with movable coatings, is placed upon an insulating stand and charged in the ordinary way, and then the inner coating is lifted out by a glass hook, so that it may remain insulated until after its removal. Next, the glass is lifted out from the outer coating, so that we have the dielectric detached from both coatings. Finally, both coatings are discharged while distinct from the dielectric, and the condenser is then put together again. When thus restored to its former disposition it is found to contain almost as strong a charge as it contained originally before the charges resident upon its two coatings were removed, an evident proof that nearly the whole of the charge is contained in the dielectric, and not in the metallic coatings.

Again, a gradual dragging of the particles of unmixed ether further and further into the dielectric as the ether radiation is continued, and a consequent increased difficulty experienced by the ethers in extricating themselves when

discharge occurs, are incidents which we should naturally look for if the state of things is as we have argued, and we have the following proofs that these are incidents of the charging of a condenser.

When an electric condenser, whose dielectric is glass or shellac, say a Leyden jar, has been discharged by connecting its two coatings, if we wait a short time we can obtain another, but much smaller spark by again connecting them, and other sparks may sometimes be obtained after further intervals. These are called secondary discharges, and the electricity which thus remains after the first discharge is called the *residual charge*. The amount of this residual charge depends, not only on the actual amount of the charge imparted to the condenser, but also has reference to the time elapsed since the condenser was charged; it is, in fact, not of instantaneous production when a Leyden jar is charged, but grows in quantity for some time after the introduction of the charge; thus, it is found that after a Leyden jar is charged up to a moderately high potential, the outer coating being in contact with earth, a gradual fall of the potential occurs. This fall, which is rather rapid at first, gets slower and slower until it reaches a certain limit, after which a sensibly constant loss still continues, which is, however, under favourable conditions, but small. If the condenser be charged again to bring it up to the potential reached when the sinking of potential began, the rate of fall or loss is found to be much less than before, and to be not far from the constant limit just referred to. The process may be repeated, and when the rate of loss is thus made sensibly constant the jar is said to be saturated. That the residual charge is quite withdrawn from active participation in the motions of the free portion of the charge has been shown by Kohlrausch's investigations, in which he has proved by measurements taken with an electrometer and a galvanometer that the ratio of the free, or disposable,

charge to the potential is constant, and thus independent of the residual charge. The same investigator has also concluded from his experiments that the amount of charge which becomes latent is proportional to the initial potential, that is, operating with the same jar. He has also arrived at the important conclusion that the time which a residual charge of given amount takes to reappear fully may be different according to the way that charge is produced; the charge reappears more quickly when it is produced in a short time by an initial charge of high potential, than when produced by a charge of lower potential acting longer.*

Again, the entirely material nature of the entanglement of the ethers in the dielectric, so that we seem to have pictured to us the material particles of unimolecular ether mixed in with the molecular matter, is forcibly suggested by the experiments of Hopkinson, which go to show that *two residual charges of opposite sign may be superposed, so that when the discharge occurs they shall appear in succession*. In the same direction we have Hopkinson's observation that tapping upon the dielectric facilitates the liberation of the residual discharge.

Kohlrausch states that his results have led him to suspect that the "latent" charge is greater for a greater thickness of the dielectric.

Faraday made a variety of experiments on the subject, and found the proportions of positive and negative electricity entangled in the dielectric were equal. He concluded that the cause of the phenomenon was an actual penetration of the two electricities into the dielectric, which he referred to conduction, and appealed to his experiments as showing that the difference between conductors and non-conductors is only one of degree.

* "Enc. Brit.," Art. "Electricity," p. 39.



The amount of increase of containing power in condensers is shown to depend on the material of the intervening non-conductor or dielectric. Without going into figures, it may be stated that, other things being equal, the capacity of a condenser is found to be greater when the insulating medium or "dielectric" is shellac than when it is air. The ratio of the capacity in the former case to that in the latter is called the *specific inductive capacity* of the shellac. The corresponding ratio has been found to be less for glass, and greater for sulphur. Boltzmann has also recently discovered that there is a decrease of the specific inductive capacity of gases when rarefied. This fact is evidently in harmony with the suggestion that the density of unimolecular ethers present within molecular masses is to some extent proportionate to the density of the atoms composing these masses (see p. 27).

Boltzmann obtained the important result with respect to a certain crystalline sphere of sulphur that the specific inductive capacity was different in the directions of three different axes, and this also appears to admit of an explanation in harmony with our theories; for the capacity of condensers for storage of the ethers will evidently partly depend on the permeability of the dielectric to these ethers, and we may suppose that in crystals not of the regular system this permeability is different in the directions of different axes.*

Effects of the Application of Electricity to Molecular Matter.

A number of phenomena produced by electrical discharges may be explained in accordance with our theories by supposing that accumulations of the unimolecular ethers are produced by the motions of the unmixed ethers of the

* The similar fact as to propagation of light through crystals not of the regular system is referred to subsequently (see p. 272).

discharge,* and that these unimolecular ethers, being much more tenuous than the ethers composing the molecular matter with which they come in contact, cause atom expansion and atom explosion to occur in this molecular matter. Phenomena capable of such an explanation may, it is clear, be cited as supporting the suggestion made when we entered on the present branch of our subject, that electricity is the condition of molecular matter which is brought about by contact with a body of one kind of ether present alone (p. 64).

To mention some examples :—

The discharge of a battery through a fine metallic thread produces the molecular disturbance known as incandescence, an effect which in a subsequent chapter is attributed to concerted atom explosion (see p. 202).

Of cases in which molecular matter is displaced or volatilized by electricity, we may refer to the familiar experiments of puncturing a card or a pane of glass with the charge. The interesting observation has been made that in perforating a card, if the points between which the discharge occurs be not opposite to each other, the perforation takes place close to the negative point, but if arrangements are made for exhausting the air, it is found that as the density of the air is diminished the perforation takes place nearer to the centre.

Then we have those very palpable cases in which general explosion of the mass occurs through the passage of electricity. Gun-cotton, even when saturated with water, is readily exploded in this way,† and other very familiar illustrations are presented by the explosion of certain

* Accumulations of intermixed unimolecular ethers are subsequently argued to be productive of heat, and most of the phenomena we are alluding to may be regarded as results of heat as a secondary cause.

† A further reference to the subject of explosives is made subsequently.

gaseous mixtures in the instrument known as Volta's pistol.

Some milder effects produced in the same way may be mentioned.

When a strong electric discharge passes through a fluid, pressure is suddenly transmitted through the fluid in all directions, and, if it be enclosed in a tube, the tube is generally broken, even when the spark is by no means long. When the surface of the liquid is free, a considerable portion is projected into the air.

The researches of Dr. Warren de la Rue and Dr. Hugo Müller with a very large chloride of silver battery, have of late given the most unquestionable evidence of sudden and considerable molecular expansion produced by electrification, and that quite apart from the increase of volume due to heat. The experiments were made in a bell jar, containing the terminals, and the jar could be gradually exhausted after having been filled with air, or other gas. The remarkable phenomenon was observed, on making connection between the terminals and the battery, that, within certain limits of pressure in the bell jar, a sudden expansion of the gas took place, and that as soon as the connection was broken the gas then as suddenly returned nearly to its original volume, though not quite, in consequence of a slight increase of temperature. The effect was exactly like that which would have been produced if an empty bladder had been suspended between the terminals and suddenly inflated, and as suddenly emptied.*

The following phenomena are additionally interesting, on account of the support they afford to our theories of capillary action :—

If two small balls, connected with the electrodes of a Holtz's machine in action, be dipped in paraffin oil at a

* Taken from *Nature*, No. 556, p. 174, where details will be found.

small distance apart, the whole liquid is thrown into violent motion and runs up the wires which lead to the balls, spouting off in little jets ; further, a heaping up of the liquid is observed between the balls, and if one of them be gradually withdrawn from the liquid for a centimetre or so, it raises a column after it, which adheres until the machine is stopped.*

The explanation we have to submit is this : We have argued that forces of capillary attraction, and of gravitation everywhere act perpendicular to surfaces throughout which equal density of the unimolecular ethers prevails (p. 51), and we suppose that the presence of the unmixed ethers which are passing from the electrodes, changes the direction of these surfaces of equal ether density in such a way as to make the surface of the liquid, in seeking equilibrium under the surface attraction to which it is subjected, exhibit the changes observed.

Again, Faraday observed that a large drop of mercury, resting on the flat bottom of a vessel containing dilute acid, changes its form in a remarkable way when connected with one of the electrodes of a battery, the other electrode being placed in the acid. When the mercury is made positive, it becomes dull, and spreads itself out ; when it is made negative, it gathers itself together, and becomes bright again.†

In this case changes of ether distribution and density within the molecular masses of mercury and acid, adequate to produce the effects observed, should perhaps be partly, or entirely attributed to changes in the quantity and proportions of the ethers liberated within these masses, caused by the electric action.‡

* "Enc. Brit.," Art. "Electricity," p. 66.

† Taken from "Enc. Brit.," Art. "Capillary Action," p. 65.

‡ That electric action does sometimes produce this effect is argued, p. 195.

As a final example of capillary change produced by electricity, we may mention the familiar experiment of the electric bucket. When a vessel containing a liquid, and furnished with very fine discharge tubes, is suspended from the conductor of the machine, so long as the vessel is not electrified the liquid comes out drop by drop ; but when the machine is turned it issues in continuous fine streams, the quantity discharged in a given time being sensibly the same in both cases.*

The lowering of the cohesion of the liquid which this effect indicates would, according to our theory of the nature of the liquid state, be naturally accounted for by supposing molecule destruction within the liquid, and consequent internal ether liberation, to be increased by the presence of the unmixed ether of the charge.

In connection with this explanation we may mention the fact first ascertained by the Abbé Nollet—1746 to 1753—that electricity increases the natural evaporation of fluids, and that the evaporation is hastened by placing them in non-electric vessels.†

Some further important references to the influence of the unmixed ethers on molecular matter will be made in the sequel, when we deal with the subject of Chemistry.

* "Deschanel's Electricity," edited by Prof. Everett, p. 558.

† The same observer also ascertained that the vegetation of seeds is hastened by electrifying them.

CHAPTER XII.

ELECTRO-DYNAMICS.—*Continued.**Electric Currents of Long Duration, or Continuing Currents.*

THE well-known phenomena of electricity, which we have touched upon, lead us to conclude that ethers moving by conduction have very great velocity, and also that the presence of any large store of unmixed ether will ordinarily be accompanied by violent action of molecular matter. It is, in consequence, somewhat difficult at first sight to conceive of the existence under ordinary conditions of a current of ether which shall have unbroken continuance, and yet not be immediately, or almost immediately, exhaustive of its source, and therefore of very short duration; a reference to the continuous motions of some grosser forms of matter will, however, it is thought, lessen the difficulty.

In the case of the apparatus arranged to supply the upper floors of our houses with hot water, the pipes are, as we know, arranged to produce what is called a hot water circulation, and, as this name implies, a continual flow of water traverses the pipes of the circulation in one direction, heated water continually rising from the boiler through one of its connections, and the same water, somewhat cooled, returning to the boiler through another of its connections, and one small cistern contains water enough to keep up the continual flow, because the same water is used over and over again.

Again : We have another instance of continued flow in the case of a steam boiler, a current of steam being continually emitted whose total bulk is enormously greater than that of the boiler.

We suppose that a continuing electric current is an ether current in which conditions are present akin to those of both these cases of continuous flow, and that we have generally (1), A complete circuit of conduction ; (2) A continuous liberation of unmixed ether somewhere in this circuit. Further, that such a current resembles an ether current of short duration, such as we have already treated of in three points, namely,—

1. In the motion of one kind of ether generating a motion in the opposite direction of the other kind of ether, so that two opposite currents of the two ethers are always present in an electric circuit* (see p. 75).

2. In *equal* currents of the two different ethers *when they intermingle*, neutralizing each other electrically.

3. In the possibility of drawing off electricity from a current, by conduction, just as we should from a charged conductor.

And that, on the other hand, it differs from an ether current of short duration in the following points:—

- a. That while two *short* currents, one of positive, the other of negative ether, travelling simultaneously along a uniform conductor in opposite directions, if they ever meet, cannot without ceasing to be currents continue together ; two *continuous* currents of opposite kinds, thus travelling along a conductor which forms a continuous circuit, *may be regarded as both simultaneously present at every point in the circuit.*

* This harmonizes well with experiment and with the statement made in treatises on electricity, that every electric current may be regarded as a flow of positive electricity in one direction, and of negative in the opposite direction.

b. That while the electrical energy of a short current depends on the difference of electrical potential at the two points between which it is set up, such a current ceasing so soon as this difference comes to an end, the electrical energy of *a continuous current*, at any point of its course, depends not only on differences of potential, but also on the quantities of ethers which for the time being are kept unmixed, and which, but for the existence of the current, would be intermixed and neutralizing each other electrically.*

It should be added to the above, however, that in cases when the earth forms part of the circuit, notably in cases of long currents, we may suppose that the unmixed ether of one kind which passes into the earth at one extreme of a conductor does not find its way through the earth to re-enter the conductor at its other extreme, but merely that the same quantity is drawn from the unimolecular ethers within the earth at one end as passes out from the conductor at the other end.

Consistently with the above theory of the nature of electric currents, we suggest that the following is the difference between electromotive force, and strength of current, or supply of electricity.

Electromotive force between any two points, or difference of electric potential between them, depends, according to our theories, on the quantity of one unmixed ether in excess of the other at each of the two points, and is therefore independent of all unmixed ethers, present anywhere between the points at any moment, which consist of the two kinds in equal proportions, *i.e.*, in such proportions that if intermixed they would neutralize one another.

Strength of current, on the other hand, depends on

* As we have said, the presence of intermixed unimolecular ethers is subsequently argued to produce heat.

the quantity of the two ethers separated in the current irrespective of the distribution of potential, being regulated, it is supposed, by the quantity of the two ethers passing a given point in the conductor in unit of time.

According to this, what is known as a strong current at low potential, is a current consisting of a large body of moving unmixed ethers, but so distributed that the proportions present at any given point, if intermixed, would nearly neutralize each other.

As to the origin of motions of continuous chains of similar ether particles, such as we thus suppose constitute electric currents,—

We have suggested (p. 67) that in all bodies small masses of intermixed unimolecular ethers are continually here and there temporarily separated into their constituents by the disturbances to which we suppose all matter to be continually subjected ; and it is evident that if this be so, we must everywhere have now and then small quantities of unmixed positive ether and small quantities of unmixed negative ether moving towards one another as the two kinds of particles, from time to time separated, symmetrically intermix again (see p. 75).

In the absence of special conditions, small motions of the ethers, thus occurring within a conducting substance, will naturally take place in all directions equally, but in cases where electric currents occur we suppose that movements of the ethers—produced in most cases* by the liberation of different proportions of the two unmixed ethers at different places in a certain manner—*cause the small motions of the unintermixed ethers, just referred to, to have chiefly one particular direction*, and thus produce opposite currents of the two ethers in this direction.

* We must except the cases in which electric currents are set up by the action of previously existing currents, or by motions of molecular matter.

The liberation of different proportions of the two ethers at different places we suppose to be caused partly by the presence of different kinds of molecular matter at different places in the circuit, partly by the existence of different conditions of the same matter at different places.

Before we endeavour, on the lines thus indicated, to trace more precise theories of the production of ether currents in one or two typical cases, we will offer some evidence that different proportions of the two ethers are emitted by different molecular masses, and that, sometimes, from the same molecular matter the two ethers are emitted in different proportions under different circumstances.

First, as evidence that different proportions of the two ethers are emitted by different molecular masses, we have the various phenomena which have already been explained by the supposition that this is so (see pp. 47, 73, and 76, *et seq.*). And we also have the significant fact that the different behaviour of the elements when in the presence of an electric current, has led scientists to arrange the elements in an electro-chemical series, in which each term is supposed to be more electro-positive than the one preceding it, and thus to have a higher potential when the two elements are in contact.* This series, as determined by Berzelius, is given subsequently ; it is sufficient to say here that the phenomena on which it is based appear to be adequately explained if we suppose that the electro-chemical relation found subsisting between the different elements is determined by the different proportions which they emit of the two ethers ; that a considerable excess of negative ether is emitted by the element (oxygen) which stands at the head of the series, and that the proportion of positive ether emitted increases in successive terms, till, at the foot of

* The electromotive force which generally subsists at the surface of separation when two different substances are in contact is commonly called *the contact force*.

the series, we have an element (potassium) emitting a considerable excess of positive ether.

Finally we may mention, as supporting the same theory, an experiment made by Sir William Thompson :—

A ring is formed, one half of which is copper, the other half zinc. This ring is placed horizontally, and a needle made of thin sheet metal is so balanced as to form a radius of the ring. If, when the needle is unelectrified, it be adjusted so as to be over the junction of the two metals, then, when it is positively electrified, it will deviate towards the copper, and, when negatively electrified, towards the zinc. Again, if a whole, instead of a half needle as above, be suspended over a disc made of alternate quadrants of zinc and copper, or, better still, inside a flat cylindrical box constructed in a similar way, so that when the needle is unelectrified its axis coincides with one of the diameters in which the disc is divided, then, when the needle is positively electrified, it will take up a position such that its axis bisects the copper quadrants ; if it be negatively electrified, its axis will bisect the zinc quadrants.*

Next, we offer the following evidence, *that sometimes from the same kind of molecular matter the two ethers are emitted in different proportions, according to the temperature of the mass, or the chemical conditions surrounding it*,† indicating that, under different circumstances, different atoms or different proportions of the same atoms are exploded.‡

* Taken from “Enc. Brit.,” Art. “Electricity,” p. 85.

† It is argued, subsequently, that changes of temperature and chemical changes are both due to changes either in the quantity or relative proportions of the two unimolecular ethers present, which act by altering the values of the local pressures referred to (p. 31), so as to lower their minima (see Sections on Heat and Chemistry).

‡ The bearing of this on the production of electric currents will appear immediately when we examine the various instances of their

At the close of the last century, Laplace, Lavoisier and Volta found that electricity is developed when solid or fluid bodies pass into the gaseous state. The bodies which were to be evaporated or dissolved were placed upon an insulating stand, and made to communicate by a chain or wire with a Cavallo's electrometer, or with Volta's condenser when it was suspected that the electricity increased gradually. When sulphuric acid, diluted with three parts of water, was poured upon iron filings, hydrogen was disengaged with a brisk effervescence, and at the end of a few minutes the condenser was so highly charged as to yield a strong spark of negative electricity. Similar results were obtained when charcoal was burnt on a chafing dish. Volta, who happened to be at Paris when these experiments were made, and who took an active part in them, subsequently observed that the electricity produced by evaporation was always negative. He found that burning charcoal gives out negative electricity; and in other kinds of combustion he obtained distinct electrical indications. Subsequently, Saussure found that positive electricity is liberated when water is evaporated from a heated crucible of iron or of copper, but negative electricity when it is evaporated from a crucible of porcelain or silver.*

We will now, with the aid of the above, endeavour to frame theories of the production of electric currents in certain typical cases.

First, let us take the case of feeble electric currents produced by what is known as the thermo-electric pile or thermo-pile.

production without the aid of external molecular or ether motions, as it will then appear probable that a necessary condition of this production is *that differences shall prevail in different parts of the same molecular mass* such as would, according to our argument, produce from similar molecules emission of the two ethers in *different proportions at different places in the mass.*

* Taken from "Enc. Brit.," Art. "Electricity," p. 9.

The principle of this delicate instrument for determining slight differences of temperature is based on the fact that, if heat or cold be applied to *one* of the junctions in a circuit composed of two different metals, an electric current is produced in the circuit. This was first discovered by Seebeck in 1821. It may be illustrated by employing a rectangular frame having three sides formed of a strip of copper plate bent into the requisite shape, and the fourth of a cylinder of bismuth. The frame must be placed vertically in the magnetic meridian with a magnetized needle in its interior. On heating one of the junctions with a spirit lamp, the needle is deflected in such a direction as to indicate that positive electricity is flowing from the hot to the cold junction in the copper portion of the circuit, and from the cold to the hot in the bismuth portion.* If cold instead of heat be applied to one junction, the direction of the positive electricity is still from the warmer junction through the copper to the colder junction, and from this through the bismuth to the warmer junction. If antimony is employed, instead of copper, the effect is more powerful.†

According to Becquerel's experiments, the metals may be ranged in the following order as regards the direction of the current produced by heating a junction of any two of them :—*Bismuth, platinum, lead, tin, copper, silver, zinc,*

* It is usual to regard the direction taken by the positive electricity as the direction of a current.

† In constructing a thermo-pile, the effect of the difference of temperature between two junctions in a circuit composed of two metals is multiplied by constructing a circuit of a number of pieces of two metals (antimony and bismuth), so arranged that the metals are placed alternately in the circuit, and that the junctions are, as to one-half of their number, presented at one end, and, as to the other half, at the other end of the pile ; and the junctions brought together, and subjected to the same temperature, being in both cases *the alternate junctions*.

iron, antimony; that is to say, if a junction of any two of these metals be heated, the direction of the current at the junction in question will be from that which stands earlier in the list to the other. His experiments have also established the important fact that the current obtained by heating all the junctions of a chain of bars of dissimilar metals to one common temperature is the same (saving resistance) as that obtained by removing the intermediate bars, and uniting the two extreme bars directly to each other, and then heating the junction to the same temperature.*

Slight impurities and variations of physical condition are often found to alter the position of a metal in the series. Iron is a remarkable instance of such variations. Thus Joule has found the following order to hold—*cast iron, copper, steel, smithy iron*.

It has been found, too, that for every two metals there is a particular temperature called their neutral point, such that a circuit composed of these metals will give no current when one junction is just as much above the neutral point as the other is below it. This holds in every case when the difference of temperature between the junctions is small, and it generally holds as far as differences of some hundreds of degrees. If one junction is kept at a constant temperature lower than the neutral point, while the other, initially at the same temperature, is steadily raised, the current first increases to a maximum, which it attains when the neutral point is reached, then decreases to zero (according to the above law), and then becomes reversed, with continually increasing strength. These changes can be shown with copper and iron wire. For if a piece of iron wire is joined at both ends to copper wires, and the copper wires are led to a delicate galvano-

* Taken from Deschanel's "Electricity," edited by Prof. Everett, pp. 652 and 653.

meter, when one of the two junctions is gently heated, a current is produced which deflects the needle in one direction ; but if the heating is continued to redness, the needle comes back, and is still more strongly deflected in the opposite direction.*

The following explanation is offered of the simple case of a current in a circuit composed of two metals having two junctions, one at a higher temperature than the other.

In harmony with what was stated above (p. 131), we suppose that in the case of each piece of metal different proportions of the two ethers are being disengaged at the two differently heated ends, and that a difference of electrical potential subsists not only between the two ends, but also, since there is a gradation of temperature from one end to the other, between any two succeeding points in the piece.

Now, if the circuit were composed of two similar pieces of the same metal, whose ends were thus differently heated, corresponding ends coming together, it is evident that a precisely similar difference of potential would be found between the ends of one piece as between the ends of the other ; and, in the endeavour after equilibrium, we should have precisely similar flows of one kind of ether starting in opposite directions from one junction to meet similar diverging flows of the other kind of ether starting from the other junction ; and whatever effect was produced by one flow would be neutralized by the similar effect produced by the other in the opposite direction. But in the case under consideration the two ends of the one piece of metal are connected by a piece of a different metal, and we have concluded that two different elements when at the same temperature, or, to speak more generally, when subject to similar ether conditions, suffer a different

* Taken from Deschanel's "Electricity," edited by Prof. Everett, p. 654.

amount of molecule destruction, setting free different proportions of the two ethers—the difference depending on the ether constitution of the atoms of the two elements respectively—and therefore we must look for inequality between the differences of potential in one metal as compared with the differences of potential in the other metal; we may, in fact, find the order of potential reversed, one metal showing a rise from the hot to the cold junction, while the other, at the same temperatures, shows a rise from the cold to the hot; and, in any case, if the difference of potential is unequal in the two cases, the effect of the difference of potential in one piece of metal will be different from the effect of the difference of potential in the other piece of metal.

It is true that, taking the point of highest potential in a circuit and the point of lowest potential, there is the same amount of fall in both directions, but *the fall in one direction is of a different nature from that in the other*; for in one direction, where the same applied temperature produces a different electrical potential in two different metals, we have a sudden fall across a junction, while in the other direction we have a gradual fall of potential due to a gradation of temperature in the same piece of metal; and *it is reasonable to suppose that a gradual fall of potential has greater effect in producing ether motions in one direction than a sudden fall of potential to the same amount has in producing such motions in the opposite direction.*

We suppose, therefore, as suggested above (p. 129), that as a net result of the various differences of ether liberation at different parts of the circuit and consequent differences of potential, we have movements of the newly-liberated ethers along the circuit.

Finally, we suppose that these movements of the newly-liberated ethers cause the small ether motions of reintermixture continually occurring, which have been referred to



(p. 129), to have one particular principal direction, the direction of the current, and thus cause opposite currents of the two ethers in this direction.

That falls of potential to the same amount, but of different natures in a circuit, exert different effects, as just supposed, seems indicated by some experiments of Le Roux, who has shown that where there is dissymmetry in the ends of similar wire brought together at a junction—*e.g.*, where an edge of one end is pressed on the flat surface of the other, where the ends overlap or cross, or where the chisel-shaped end of one wire fits into a notch in the end of the other, and the axes of the wire are inclined, and so on—the heating of one side of the junction produces a current.

With regard to the phenomenon, above alluded to, of the reversal of the current, when the temperature of one junction is made sufficiently high, that of the other junction being sufficiently low; this evidently accords with the conclusion that the proportion of the two ethers set free by molecule destruction is different at different temperatures.

As to the fact discovered by Becquerel, that the current obtained by heating all the junctions of a chain of dissimilar metals to one common temperature, is the same as that obtained by uniting the two extreme bars of the chain directly to each other, and heating their junction to the same temperature (the junction of the end bars to complete the circuit, being in both cases at a different temperature), it is easily seen that whenever a bar has its two ends at the same temperature, there is no gradation of potential throughout it, and the ethers disengaged by the destruction of its atoms, will pass as much in one direction as in the other, and thus the bar will exercise no more influence in the production of a current in one direction than in the other. And it is, therefore, in harmony with our conclusions, that when such a bar is removed, and the

circuit closed up again without it, no alteration takes place, so far as the production of a current is concerned, saving, as has been said, the resistance due to the bar, to which reference will be made hereafter (p. 150).

Herr Schulze-Berge, of Berlin, has attempted a determination of the electric phenomena which occur on contact of metals and gases. Among other observations, he finds that ozone makes gold, platinum, and brass negative to a plate of the same metal in air ; also that hydrogen always makes platinum strongly positive, while its influence on gold is hardly perceptible, and on brass qualitatively various ; great variability was, however, generally found in repetitions of the same experiment.*

The fact that a thermo-electric current may be set up in a circuit composed of the same metal in different molecular states, we conclude to be identical with Joule's discovery, above referred to, that the same metal in different molecular states occupies different positions in the thermo-electric series. It indicates, according to the preceding arguments, that in different states the same metal emits different proportions of the two unimolecular ethers.

As an instance of the fact referred to :—If a knot or a helix be formed in a piece of platinum wire, and heat applied at one side of it, a current is indicated by a delicate galvanometer. And, as another instance, we have the following experiment due to Magnus. On a reel, formed by crossing two pieces of wood, are wound several turns of hard-drawn brass wire, softened in a number of places adjacent to each other on the reel. The free ends of the wire being connected with a galvanometer, and the parts of the wire lying between neighbouring hard and soft portions being heated, a thermo-electric current of considerable strength is obtained, whose direction is from soft parts to hard across the heated boundaries. Effects of a

* *Nature*, No. 600, p. 617.

similar kind were obtained with silver, steel, cadmium, copper, gold, and platinum. In German silver, zinc, tin, and iron, the current went from hard to soft across the hotter boundary.* As further instances:—Sir William Thompson has obtained similar results, in the case of the same metal subjected to different degrees of strain. And, finally, it is not uncommon in the case of metals which are usually heterogeneous in their structure, such as bismuth, to find currents produced by heating parts which appear quite uniform.†

The experiments of Magnus have shown, that where every part of a circuit, composed entirely of one metal, is in the same state as to hardness and strain, no thermo-electromotive force exists, no matter what the variations of the section or form of the conductor, or what the distribution of temperature in it may be, so long as there is neither discontinuity of form nor abrupt variation of temperature.‡

A property of circuits composed of dissimilar metals, the converse of that above referred to, was discovered by Peltier.

He found that when an electric current passes over a junction of antimony with bismuth, in the direction from the former to the latter, there is an increase of temperature at the junction, and, when the current passes in the opposite direction, there is a decrease.

An explanation of this will be attempted when we come to consider the subject of heat.

The flow in opposite directions of the two ethers in a circuit, due to ether motions arising from interaction between different metals, which has just been explained, seems to be exemplified by an experiment made by Volta, of which the following is a simplified form.

* "Enc. Brit.," Art. "Electricity," p. 95.

† Deschanel's "Electricity," translated by Prof. Everett, p. 653.

‡ "Enc. Brit.," Art. "Electricity," p. 95.

The upper and lower plates of a condensing electroscope are made of different metals, say copper and zinc respectively. Let the upper plate be laid upon the lower, and the metallic contact ensured by connecting them for an instant by means of a wire. If the upper plate be now lifted vertically upwards, the gold leaves of the electroscope diverge, indicating that the zinc plate has become positively electrified to a considerable potential.*

We suppose that in this experiment, during the instant for which the plates are in metallic contact, a flow of the two ethers takes place in opposite directions, which drives negative ether into the dielectric next the copper, and the complementary positive ether into the dielectric next the zinc, and that the ethers remain stored up in the dielectric, as previously explained, so long as the plates remain together, but are released when the upper plate is lifted (p. 116).

Let us next endeavour to explain the production of electric currents in what is known as a *Voltaic Battery*.

The simplest form of Voltaic battery, that which Volta, the discoverer of this means of liberating electricity, originally experimented with, consists of a pile of a number of pairs of zinc and silver plates, separated from each other by pieces of wet cloth. Hence, the order of the layers, starting, say, from the bottom, is zinc, wet cloth, silver, zinc, wet cloth, silver, and so on; the lowest plate of all is zinc, the highest silver. When the highest and lowest plates are connected by a conducting wire, a current is found to be traversing the circuit thus completed, positive electricity passing from the bottom plate of zinc up through the pile to the top plate of silver and down through the wire.

Now, if we disregard the cloth, which we will suppose

* "Enc. Brit.," Art. "Electricity," p. 83.

is merely a receptacle for the water, we have here four elements, namely, zinc, silver, and the two components of water, oxygen and hydrogen.* To trace the effect of these elements on each other is the function of chemistry, and therefore properly belongs to a subsequent chapter, but we must slightly forestall the treatment of the matter here.

Confining our attention to a single layer of each substance—*i.e.*, to one segment of the pile,—consisting of a plate of zinc, a layer of water, and a plate of silver, we observe first that, judging by the position of the zinc in the electro-chemical series to which reference has been made, positive ether predominates in the unimolecular ethers emitted by this element, that the proportion of positive ether is less in the emissions from the element silver, and still less in those from the element hydrogen, while in the ether emissions from the element oxygen negative ether very largely predominates, this element being indeed, as already remarked, at the head of the electro-chemical series.

If, therefore, as already argued, molecule destruction is everywhere going on, and the metals and the water both have unimolecular ethers in a highly condensed state present among their molecules, we may conclude that, at any given moment, the zinc will have present within it a greater excess of positive ether than is present in the water, and that as the excess of positive ether in the zinc proceeds to intermix symmetrically with the excess of negative ether in the water, a small flow of positive electricity will take place from the zinc towards the water, and a small flow of negative electricity in the opposite direction, from the water towards the zinc.

A similar effect, in which, however, the movements of the respective ethers have the opposite directions, will, we

* The theory of chemical combination subsequently offered will be found to justify the supposition that the qualities of the individual elements composing a compound are traceable in the compound.

must conclude, take place between the silver and the water ; but as this will, judging by the relative positions of the zinc and the silver in the electro-chemical series referred to, be less considerable than the effect produced between the zinc and the water, the net result, according to the arguments used with respect to a thermo-electric circuit, will, presumably, be the production of a feeble current in the circuit, in which the direction of the positive ether is from the zinc towards the water.

To account for the comparatively strong current actually found, we must carry the argument a step further.

The unmixed positive ether which is moving in one direction, and the unmixed negative ether which is moving in the other, will have their movements checked, and symmetrical intermixture with one another facilitated wherever they encounter the less-conducting material—the water—and thus *at the boundary, between the zinc and the water, an accumulation of the intermixed unimolecular ethers will take place.* And if we suppose that the molecular nature of the zinc and also of the water is such that the presence of an accumulation of the unimolecular ethers in contact with them produces considerably increased atom expansion and molecule destruction,* we have a source of considerable liberation of unmixed positive ether from the zinc and unmixed negative ether from the water, such as would, in the way already explained, supply motive power adequate to set up comparatively strong currents of the two ethers in the circuit.

As in the case of thermo-electric currents, we suppose that the moving ethers of the currents are largely, and, indeed, chiefly drawn from the general mass of unimole-

* See p. 24.

The facts that heat and chemical action are produced are, according to subsequent reasoning, evidence of the occurrence of these changes.

cular ethers present in the circuit, the function of the freshly emitted ethers being chiefly directive, determining that the motions of reintermixture of the unimolecular ethers which are above referred to (p. 129) shall take place chiefly in one particular direction.

The efficiency of silver, as the other metal employed with the zinc, appears to lie in its furnishing a good conductor to the ethers moving in the circuit, and in its not being readily acted on by any accumulations of intermixed unimolecular ethers;* for if it were readily acted on, we should have ether liberation tending to set up currents similar to those set up by the zinc, but in the opposite direction.

The repetition of the layers, which constitutes the voltaic pile, it is suggested, merely intensifies the effect by continually adding impetus and volume to the positive ether travelling in the one direction, and to the negative ether travelling in the other direction.

It is suggested that the material point in which the various voltaic batteries differ from the original voltaic pile, which has just been explained, is, that the liquids they contain in place of simple water are of a nature to produce greater molecule destruction, and consequent greater ether emission; this would account for the stronger currents obtained.

Cruikshank's trough battery, for example, consists of a rectangular box, or trough, of baked wood (which is a non-conductor) divided transversely into compartments by partitions, each consisting of a plate of zinc and a plate of copper soldered together; these partitions all have their copper faces turned towards one end of the trough, and, consequently, all their zinc faces towards the other end, and the compartments formed have dilute acid poured into them, to take the place of the water in Volta's pile.

* According to subsequent arguments the silver remaining practically unchanged is evidence that this is so.

And the considerable ether motions, which we suppose the strong action of such a battery indicates, we attribute to the large proportion of electro-negative elements which is present in the liquid employed ; this, according to the arguments above given, being productive of stronger motions of newly-liberated ether, and more considerable accumulations of the intermixed molecular ethers to act on the molecular matter.

In harmony with these views, the well ascertained fact, that no pile or battery can generate a sensible current except by a sensible consumption of its materials in chemical action, is interpreted to indicate that molecule destruction is always the ultimate cause of electric currents.

The following definitions apply to galvanic batteries generally :—

The difference of potential between the two terminal plates, or extremes, of a battery is called *the electromotive force of the battery*. Its amount is commonly measured by means of *Thomson's quadrant electrometer*.

These terminal plates, or extremes (that is, the zinc of the first and the copper of the last cell where zinc and copper are used), are called *the electrodes or poles* of the battery ; these names also being extended to the conducting wires in contact with these extremes.

As already stated, *the direction in which the positive electricity passes* is spoken of as the direction of the current.

When the plates are of zinc and copper, the zinc is the negative, and the copper the positive electrode ; and this, according to the above theories, indicates that the positive ether flows *through the cells* from the zinc to the copper, and the negative ether from the copper to the zinc.

It is unnecessary to describe here the numerous varieties of galvanic batteries which have been invented ; but we

shall refer to one or two typical batteries for the purpose of calling attention to some interesting phenomena associated with voltaic action.

The battery known as *Hare's deflagrator* consists of two very large plates of zinc and copper rolled up together upon a central cylinder of wood, thus forming a helix in section. The plates are prevented from touching each other by pieces of cloth or twine inserted between them. The roll is plunged in a tube of acidulated water, and terminal wires connected, one with each plate. This form of battery furnishes strong currents of comparatively low potential, which, when checked by reduced conduction, produce great heat effects.

The explanation offered of this feature, to which the battery owes its name, is as follows :—

If, as we have supposed, an electric current consists of the two ethers unintermixed with each other moving in opposite directions, the strength of a current, or amount of ethers composing it, will largely depend on the degree of conduction afforded in the circuit; if the conduction is good, or, in other words, the flow of the unmixed ethers comparatively uninterrupted, we may look for a strong current. On the other hand, ready conduction will tend to equalize potential, and may therefore be expected to be associated with low electromotive force.

The strong currents of low potential given by a Hare's deflagrator appear, therefore, to be the natural result of its low internal resistance to the passage of the unmixed ethers.

A defect to which all *one-fluid* batteries are more or less subject is called *local action*. It is the action which still goes on at the surface of the zinc exposed to the acid solution when the external communication between the plates is broken. It is generally supposed to arise from inequalities in the zinc, which render one portion of its

surface electro-positive to another portion, and cause minute currents to pass just as between plates of two different metals. And this explanation is shown to be reasonable by the fact that a very sensible current may be obtained if we use one metal only instead of two to form the plates of a galvanic battery, provided the metal be in two different states. Thus, by melting zinc repeatedly, and pouring it into cold water, a metal is obtained on which dilute sulphuric acid acts very feebly ; and if a plate of this metal is used with a plate of ordinary zinc, a battery cell may be formed with these instead of with zinc and copper.

That this is the correct view of the cause of local action is also indicated by the fact that it specially occurs with ordinary commercial zinc, and that the evil is remedied by amalgamating the surface of the zinc plate.

What is known as *Ritter's secondary pile* appears to furnish an instance of a metal passing temporarily into different electro-chemical states.

This instrument consists of a number of discs, all of the same metal, separated by pieces of moistened cloth. If its two extremities be connected for a few seconds with the poles of a battery, the pile is found to have acquired the power of producing for a short time a current opposite in direction to that which proceeded from the battery.

The explanation we have to offer is, that exposure to the different potentials of electrification found at the two poles of the battery, like exposure to different temperatures, produces different degrees of molecule destruction in discs differently situated in the series (see p. 132), and thus causes them to act like different metals, or like the different qualities of zinc above referred to. Perhaps, however, the phenomenon is partly due to actual storage of the ethers, such as is referred to immediately (see p. 149).

There are two serious preventives to the continued

action of galvanic batteries. One of these arises from the chemical action between the zinc and the acid (where zinc is used), producing a chemical compound, and gradually impoverishing the acid solution, so that it becomes less and less capable of acting on the zinc. The other, which is the more serious, is known as *polarization*, and is quite universal in galvanic batteries, so that when a battery is first started the initial electromotive force disengaged always begins to fall off from this cause; and the same thing occurs whenever we insert an electrolyte into any current. Polarization, which is due to the alteration of the plates (electrodes), is a phenomenon which deserves our attentive consideration for a few moments, as there are some features of it which are very suggestive in connection with the foregoing theories.

Two different kinds of change at the surface of the electrodes are productive of polarization. Thus, if we compare the effects in a cell containing concentrated sulphuric acid, in which is inserted two electrodes of copper, with those in a similar cell in which electrodes of platinum instead of copper are employed, we find that in both cases the insertion of the cell into a current weakens the current, but that they differ in the following respect—that in the first case a definite compound, copper oxide, is formed upon the surface of the positive electrode, but that in the second case the oxygen is merely deposited upon and within the positive electrode in a highly condensed state; that it is, in fact, in the latter case, as there is reason to believe, alloyed with the platinum of the electrode.* The difference in the effects consequent on these two different kinds of change is clearly shown if we test the positive electrodes against fresh plates of similar metal; for we find that the platinum plate which served as posi-

* See Note *, p. 340.

tive electrode then gives a strong current, whereas the corresponding copper plate gives scarcely any.*

It seems probable that in the case of the oxidation of the copper electrode the polarizing effect is partly due to the loss of conductivity in the circuit, this retarding the two ethers of the current and facilitating their intermixture; but it may also be partly due to additional ether liberation *occurring at the oxidized surface during the passage of the current, and producing a counter current.*

As to the other case, that of the platinum electrodes, the following facts are generally regarded as proofs that the polarization is due to a change in the plates employed:— (1) The substitution of a fresh plate, in place of the polarized plate, immediately restores the electromotive force of the current. (2) The deposited gas may be removed by washing the plate with water, potash, or nitric acid. (3) The polarized condition may be produced without inserting the plate in a current at all, if platinum be alloyed with oxygen, by bringing it into the presence of this element in the form of ozone. †

The cause of the phenomenon is probably twofold: For, first, we observe that the change in the platinum plates arising from the occlusion of gas, in other words, from their being alloyed with another element, will be likely, according to our arguments, to cause them to emit a different proportion of the two ethers, and will thus account for

* "Enc. Brit.," Art. "Electricity," p. 87.

† A plate of platinum is rendered *electro-positive* to a fresh plate if it is alloyed with hydrogen by immersing it in this gas.

The competency of different gases to produce different states of the same metal, is well shown by the gas battery of Grove.

Two long glass tubes, A and B, are arranged in the two necks of a Woulfe's bottle. The upper ends of the tubes are closed, but pierced by two platinum wires, to which are fastened two long strips of platinum foil (which are sometimes platinized), reaching to very near the lower ends of the tubes. The bottle and part of the tubes

polarized plates, used with fresh plates, acting like two different metals as above stated. Secondly—and this having regard to the considerable secondary currents sometimes produced by polarization, is, perhaps, the principal cause—the alloying of the plates with condensed gas will, we conclude, to some extent, destroy their conductivity, and cause them to act as electric condensers, so that they are able to entangle and store up some of the ethers of the current, to give them up subsequently in a direction opposite to that from which they came.

It is interesting to notice the great rapidity of the rise and fall of polarization which sometimes occurs. Thus, for instance, Edlund has found that in a certain case the electromotive force of polarization reached $\cdot 057$ of a Daniell in about $\frac{1}{50}$ th of a second, and Bernstein has recently stated that platinum plates, polarized to $1\cdot 85$ of a Daniell, fell, when the resistance of the circuit was $7\cdot 46$ Siemens units, to $1\cdot 57$ in $\cdot 00111$ seconds.

The electrolytic action by which the hydrogen passes in the same direction as the positive current is explained hereafter.

are filled with some liquid, say dilute sulphuric acid, and hydrogen is introduced into B, and oxygen into A, either by sending an electric current from A to B, and decomposing the dilute acid, or by some other means.

This arrangement has an electromotive force comparable with that of a Daniell's cell, and if the original volume of hydrogen in B be twice that of the oxygen in A, it will continue to send the current through a closed circuit, the gas gradually disappearing in the tubes until none is left, when the current stops. (*See "Enc. Brit.," Art. "Electricity," p. 87.*)

CHAPTER XIII.

ELECTRO-DYNAMICS.—*Continued.**Electrical Resistance—Ohm's Law.*

IT is found that the gradual fall of potential in the direction of the current, found subsisting in a uniform portion of a thermo-electric circuit, is a perfectly universal condition in all electric circuits, so that it may be stated generally ; that when a steady current is flowing through a galvanic circuit, there is a gradual fall of potential in every *uniform* conductor which forms part of the circuit, the fall being in the direction of the current. As in the case of thermo-electric circuits, the gradual falls must, it is evident, be exactly compensated by the abrupt rises (diminished by the abrupt falls, if any) occurring between the various dissimilar bodies forming part of the circuit, and which abrupt rises or falls will be attributed to the liberation of ethers through atom destruction occurring in different parts of the circuit.

If we neglect the effect of ethers set free through atom destruction occurring in a uniform good conductor forming part of a galvanic circuit, the gradual fall of potential in such a conductor is, it is suggested, due to the continual withdrawal from the current of equal quantities of the two ethers from time to time symmetrically intermixing. Thus if the quantity of positive ether passing a given point in the conductor in unit of time is a , and the quantity of negative ether passing in the opposite direction, another given point further along the same conductor, in a unit of

time, is b , we suppose that the cause of the lower potential found at the second point, is that a certain quantity, c , of positive ether is withdrawn between the two points, reducing the quantity passing the second point, in unit of time, to $a-c$; and that this withdrawal is due to symmetrical intermixture of this quantity, c , of positive ether with an equal quantity, c , of negative ether, thus reducing the quantity of negative ether passing *the first* point, in unit of time, to $b-c$.

In this case the total quantity of both ethers withdrawn will evidently be $2c$, and the excess of positive over negative ether passing in unit of time, will be less (algebraically) at the second point than at the first by the same quantity $2c$.

The theory that the gradient of potential is caused by the symmetrical intermixture of the ethers of the current, is supported by the fact that heat is always produced; for we shall presently submit evidence that heat is caused by the presence of symmetrically intermixed unimolecular ethers.

It is further supported by the fact that when we compare similar conductors composed of different material, we find, other things being equal, that the steepest gradients of potential occur in substances which are bad conductors, this being what we should naturally expect if the "*resistance*," as the power possessed by a conductor of causing a gradient in potential is usually called, is due to symmetrical intermixture, and if, as we naturally conclude, non-conductors favour intermixture, not only by hindering the passage of the unimolecular ethers, but also by the vigorous molecular motions we have attributed to these bodies.

In consequence of the fact that bad conductors give steep gradients of potential, or high *resistance*, it is customary to regard the order in which conducting bodies stand as to resistance as the order of their conductivity.

All experimenters agree in concluding that gold, silver, and copper manifest least resistance.

The order of least resistance is found experimentally to be the same as the order of thermal conductivity, in other words, the order of resistance is precisely the inverse order of thermal conductivity.

The suggestion that greater resistance is due to greater intermolecular motion, and consequent checked conduction, receives support from the following :—

The resistance even of the best conducting liquids, except mercury, is enormously greater than that of metals. For instance, in round numbers, the resistance of dilute sulphuric acid is a million times, and that of solution of sulphate of copper, ten million times greater than that of pure silver. The resistance of pure water is very much greater than either of these.*

The specific resistance of pure metals goes on increasing continuously as the temperature rises. At the melting point there is a sudden rise in the resistance, except in the cases of bismuth and antimony, which manifest a decrease of resistance at the melting point. The sudden rise in the resistance referred to is in harmony with the supposition that intermolecular motions are much more considerable in the liquid state than in the non-cellular solid state ;† also with the conclusion, which we shall subsequently endeavour to establish, that heat increases molecule destruction, and therefore molecular motions in metals (see p. 318).

As to the two exceptions we have mentioned, we suppose that the solid state of these metals is the cellular solid state, and that matter which is in this state is traversed by vigorous wave vibrations, which hinder conduction (see p. 70). And this view is seen to be in harmony with the fact that, as a general rule, metals manifest more resistance in the hard

* From Deschanel's "Electricity," edited by Prof. Everett, p. 670.

† See p. 29.

than in the soft state, the hardening being, it is suggested, an indication of a change towards the cellular solid state. Thus, tempering steel increases its resistance considerably, but subsequent heating and gradual cooling reduce the resistance again.

It is interesting to notice that alloys generally have a greater resistance than that of either of their components, and particularly that there are four metals, lead, tin, cadmium, and zinc, the admixture of ever so small a quantity of which with other metals greatly increases their resistance.

A very small percentage of another even worse conducting metal raises the conductivity of mercury, but the addition of a larger quantity lowers the conductivity.

The fact that slight impurities greatly deteriorate conductivity, especially shown by the case of copper, which often has its resistance increased by impurities to the extent of 50 or even 100 per cent., is, it is suggested, due to the impurities producing a change towards the cellular solid state.

The co-efficient of resistance of the material of a wire is increased when it is stretched by a weight.

Magnetization is sometimes found to affect resistance.

Finally, the variations of resistance of selenium, which have furnished such important results in some modern applications of electrical force, are very suggestive. Thus in an amorphous state, which, we suppose, is an example of the cellular solid state, selenium has its lowest specific gravity, 4.3, and in this state it is found to be a non-conductor. After continued heating, however, it passes into a crystalline state, which we suppose to be also a cellular solid state, but having its cells formed by the expansion of different atoms from those expanding in the former state. In this state its specific gravity is about 4.80, and it conducts, but the conditions of equilibrium of

its molecules are now so nicely balanced that the slightest changes of temperature, or exposure to light, produce changes in its electrical resistance, indicative, doubtless, of molecular changes.

The theory of the producing causes of resistance, suggested above, may be summarized as follows :—

(1). Resistance is the direct result of the symmetrical intermixture of the opposite ethers in a current.

(2). This intermixture is facilitated by any intermolecular motions which break ether continuity, and thus hinder the progress of the ethers of the current.

(3). Such intermolecular motions are considerable in liquids, as shown by their mobility, and in substances in the cellular solid state, because of the varying elasticity of their particles, and of the presence of cells filled with partly expanded ether.

(4). Any cause which increases molecule destruction within bodies, or effects any other molecular change tending to disturb the continuity of their particles, increases resistance.

Ohm's Law.

The difference of potential at the two extremities of a given uniform conductor, is shown experimentally to bear a practically constant ratio to the strength of current passing, so that if E stands for this difference—i.e., for electromotive force—and C for the strength of current; $\frac{E}{C}$ = some constant R , the value of which depends on the dimensions and material of the conductor, and is, according to the above arguments, a measure of the ether-intermixing power of the given conductor. The relation expressed by this equation, in which R may thus be regarded as the *resistance*, is called *Ohm's law*.

The following experimental proofs of Ohm's law have been given by Pouillet.

1. *For thermo-electric currents* he employed two thermo-electric elements, each consisting of a stout cylinder of bismuth with its ends turned down and soldered to copper wires. The two elements were arranged side by side, and the junctions at one end were immersed in hot water, those at the other end being kept in melting ice. The hot and cold junctions of the one were connected by a wire which was carried round a galvanometer needle.* Those of the other were connected by a wire ten times as long, which made ten times as many turns round the same needle in the opposite direction, so that the two currents opposed each other in their action on the needle. It was found that the needle remained at zero, showing that the current in the short wire was ten times as strong as the other, for one of its convolutions was able to balance ten convolutions of the other.

Now the bismuth portions being identical in the two circuits, and so large as to give an effect compared with which the current-producing effect of the copper wire is inconsiderable, it is evident that the difference of potential at the two extremes of the wire portion of each circuit, *i.e.*, the electromotive force E in this portion, was practically the same in both cases, and therefore, taking the fall of potential to be uniform in each wire, that the difference of potential between the extremes of a portion of the long wire equal to the short, must be $\frac{E}{10}$. Therefore, taking the strength of current in the short wire to be c , and consequently, according to the above experiment, that in the long wire $\frac{C}{10}$, we have, for the same conductor, E varies as C , that is $\frac{E}{C} = \text{some constant } R$.

2. *For voltaic currents*, Pouillet first sent the current of a battery through a galvanometer without any interposed

* The principle of the galvanometer is referred to further on.

resistance, and observed the strength of current, c . He then introduced, successively, known lengths of uniform wire l_1, l_2, l_3 , and observed the currents obtained. Denoting these by c_1, c_2, c_3 , and taking x to denote the length of wire which would be equivalent to the unknown resistance of the original circuit, consisting only of the battery and the galvanometer,

$$\frac{c}{c_1} = \frac{x + l_1}{x}, \quad \frac{c}{c_2} = \frac{x + l_2}{x}, \quad \frac{c}{c_3} = \frac{x + l_3}{x}.$$

From any of these three equations x can be determined, and Ohm's law is verified by similar reasoning to that used in the previous case, if they all give the same value of x . This Pouillet found to be substantially the case.*

It is evident that the determination of the units of two out of the three of the entities of Ohm's equation will determine the unit of the third. In practice, the unit of c , the current has been determined—that very commonly used is known as the electro-magnetic unit; and the unit of resistance has also been determined by arbitrary reference to some particular conductor. The unit of the third, the electromotive force, has been deduced from the other two.

It has been found that if different wires of the same material are inserted in a circuit which is taken through the coil of a galvanometer, it is necessary, in order to produce no change in the deflection, for the length of the wire used to vary directly as the area of its cross section. If, as we have supposed to be practically true, the resistance of a uniform conductor varies as its length, it follows from this that the resistance also varies inversely as the area of the cross section, a relation which would justify a comparison between the carrying capacity of a uniform conductor, and that of a pipe carrying water or other

* See Deschanel's "Electricity," edited by Prof. Everett, p. 667.



liquid. It has been experimentally ascertained, that when several wires of the same length and material are arranged side by side, and thus all simultaneously introduced into a circuit, the resistance of the whole is the same as that of one wire of the same length and material, and whose section is the sum of the sections of such wires.

We gather from the foregoing the following conclusions as to electric currents.

(1). Since the moving ethers, are drawn, as we have concluded, chiefly from the body of mixed unimolecular ethers present in the circuit, the quantities of unmixed positive ether and unmixed negative ether moving in the circuit are practically equal.

(2). For any such relation as that of Ohm's law to subsist in a uniform conductor, the current strength in different parts of it must be practically the same, notwithstanding the differences in the proportions of the two ethers at different places, which we have concluded subsist. The sum of the two ethers present at any moment irrespective of their proportions is, it is evident, practically uniform in all equal portions of such a conductor, according to the above theories of the nature of a current.

(3). The fact that the resistance of a uniform conductor varies inversely as the area of its cross section appears to indicate that all parts of the interior of the conductor are equally traversed by the moving ethers, and that the unmixed ethers are not confined to the surface as in the case of statical electrification.

(4). The conclusion that for conduction to take place we must have ether continuity (p. 66) requires us to suppose that each moving ether is disposed in a layer longitudinally continuous, or in continuous longitudinal bands, each ether occupying its own portion of the conductor much in the same way, to use a rough illustration, as currents of distinct bodies of water of different temperatures are sometimes

found in the ocean in contiguity to each other, but unmixed, travelling in opposite directions or, at least, at different rates.

(5). Since the space allotted to the unimolecular ethers in a given metal wire is practically the same, whatever the strength of the current passing through it,* we conclude that the quantity of each unmixed ether present in such a wire at any moment is the same for different strengths of current, and therefore, since, as we have argued (see p. 128), strength of current is determined by the quantity of the two ethers passing a given point in unit of time, that *the velocity of the ethers moving in the wire is proportional to the strength of the current*; that the conditions are, in fact, similar to those obtaining when water passes through a pipe of given diameter, the quantity passing a given point in unit of time being a measure of the velocity.

(6). If different lengths of a given metal wire experience a like electromotive force, *i.e.*, have the same amounts of electric potential at their extremities—as in the case of Pouillet's experiments above referred to (p. 155)—we conclude that the quantity and proportion of the two moving ethers contained at any instant within equal transverse elements (thin transverse slices) taken at corresponding ends of the different lengths of conductor will be the same in all cases.†

(7). It follows that, when different lengths of the same conducting wire thus experience a like electromotive force, the quantity of ethers intermixed between the extremes in unit of time (if we neglect any ethers liberated by molecule destruction in the conductor) varies as the velocity of the moving ethers, which in this case, according to (5) above, varies as c the strength of current.

* We do not here refer to currents strong enough to produce sensible molecular change in the conductor.

† The difference between the quantities of the two ethers present at any instant in a unit element at any point in the conductor may indeed be taken to express the value of the electric potential at this point.

(8). As

- (a). It follows from (7) that the quantity Q of ethers intermixed in *equal* portions of these similar conductors of different lengths, *i.e.*, in portions in which the resistance is constant, when such conductors experience a like electromotive force, varies as $\frac{C}{l}$ (l being the variable length of the whole wire taken), and therefore varies as C^2 , since C varies as $\frac{1}{l}$ (see p. 155).
- (b). If different lengths of a similar wire conductor receive like currents C , the quantity of ethers intermixed between the extremes in unit of time varies as l , and this varies as R .
- (c). With a given conductor and a given current the quantity of ethers intermixed varies as t , the time taken.

It follows, combining these three conclusions, and choosing suitable units, that Q the quantity of ethers intermixed in a conductor $= R C^2 t$.*

The consideration of the heating effects produced in a conductor by currents of electricity is deferred till we reach the subject of heat.

* This, as will be noticed subsequently (p. 320), is the expression found experimentally by Joule to be the value of the heat evolved.

CHAPTER XIV.

ELECTRO-DYNAMICS—*Continued.**Induction of Currents—Attraction and Repulsion of Currents.*

WE will now pass to the consideration of two very important classes of phenomena connected with continuous currents, namely,—

1. Their power of induction, or of setting up other electric currents, discovered by Faraday ; and
2. The mechanical action of currents on each other, especially in producing movements in the conductors which carry them.

A very great importance attaches to these considerations because, as we shall presently conclude, they furnish valuable elucidation of the origin of magnetic force.

First, we will endeavour to place in the light of the foregoing theories Faraday's remarkable discovery of the induction of electric currents.

The results which he arrived at are thus summed up in Prof. Crystal's Article on "Electricity" in the "Encyclopædia Britannica," to which we have so frequently referred in these pages.

"Let there be two linear circuits, $ABKE$ (the primary) and CDG (the secondary), two portions of which, AB and CD , are parallel, and near each other.

"(a) When a current is started in AB , a transient current flows through CD in the opposite direction to the current in AB ; when the current in AB is steady, no current in CD can be detected ; when the current in AB is stopped,

a transient current flows through CD in the same direction as the current in AB . These currents in CD are said to be induced, and may be called inverse and direct currents respectively, the reference being to the direction of the primary. Both inverse and direct currents last for a very short time, and the quantity of electricity which passes in each of them is the same.

“(b) If the circuit AB , in which a steady current is flowing, be caused to approach CD , an inverse current is thereby induced in CD ; when the circuit AB , under similar circumstances, recedes from CD , a direct current is induced in CD . We have already mentioned that when AB is at rest, and the current in it does not vary, there is no current in CD . AB has been supposed to approach and recede from CD ; but the same statement applies when CD approaches and recedes from AB .

“(c) When a magnet is magnetized or demagnetized in the neighbourhood of a circuit, or approaches or recedes from the circuit, the effect is the same as if an equivalent* current approached or receded from the circuit. For example, imagine a small circular circuit placed horizontally, and a vertical bar magnet lowered in the axis of the circuit, with its north pole pointing down upon the circuit, the magnet may be replaced by a series of co-axial circular currents, and the motion will induce a current passing round the circuit against the hands of a watch.”†

We shall at present deal only with the two methods of producing induced currents marked (a) and (b), leaving the third, marked (c), to be considered when we are dealing with the subject of magnetism. Of (a) the following explanation is offered.

According to the theory of electric currents which has been submitted, both positive and negative ethers, which

* Equivalent in the sense of producing the same magnetic field.

† “Enc. Brit.,” Art. “Electricity,” p. 75.

before the commencement of a current were quiescent in a conductor, and satisfying one another electrically, become, when the current is started, disentangled, as it were, and put in motion, the positive ether in one direction, the negative in the opposite. Now, each continuous stream of ether thus produced will occupy some time, however short, in extending along the conductor when the start takes place; and therefore, at the instant of the starting of a current, before the flow has become practically uniform from end to end of the conductor, we must picture a wave of each ether as flooding the conductor like a tidal wave, that of positive ether moving from one end, and that of negative ether from the opposite.

We may suppose the travelling of a steep gradient of potential in this way to be equivalent to the passage of a body containing an electric charge along the path of the current; and if, therefore, an unelectrified conductor is in proximity to the current when it starts, we may conclude that electrical induction (p. 94) will cause an aggregation, or heaping up, of the other ether on this conductor, opposite each of the moving steep gradients of potential of the two ethers travelling along the conductor in which the current is started.

We have shown, therefore, that in the conductor not directly electrified there will, probably, be a steep gradient of negative ether moving abreast of the steep gradient of positive ether which initiates the current in the other conductor, and a corresponding steep gradient of positive ether moving in the opposite direction, abreast of the steep gradient of negative ether, which also initiates the current. Thus we account for the setting up of an induced inverse current in a secondary circuit, as stated in (a).

As the ebbing away of the streams of moving ethers at the cessation of a current may be similarly argued to

produce moving gradients of *fall* of potential, *direct* induced currents, referred to in (a), will have a very similar explanation.

As we should expect, sudden increase in a current, or sudden decrease, is productive of induced currents—sudden increase in the primary current producing a momentary current in the secondary circuit in the *opposite* direction, and sudden decrease, a current in such circuit in the *same* direction as that of the primary current.

Next, as to the method of induction, marked (b).

The fact that the “attracting” force subsisting between an electrified body and an unelectrified, or oppositely electrified body, varies as the inverse square of the distance, has been referred to the diminished density of the ether radiating from the charged body, in a direction away from it.

Applying this to the case of a conductor carrying an electric current moved suddenly towards another conductor, we conclude that as the conductors approach each other, the effect of the ether radiations from the currents in the one on the unmolecular ethers in the other increases, and, moreover, that from the nature of the law just referred to, the increase is more rapid the nearer a part observed of the second conductor is to the conductor carrying the current.

The effect observed may, it is suggested, be attributed to a steepening of electric potential in the second conductor, which is more rapid towards one end of this conductor than towards the other ; but the matter is difficult to trace precisely.

The reasonableness of the view of the origin of the inductive effect marked (b), just suggested, probably appears more evident from a consideration of the experiment by which the effect is usually shown. A long coil of wire, whose extremities are connected with a galvano-

meter, is so wound as to take the shape of a hollow cylinder, so that another smaller similar coil can be introduced into its interior. A current is passed through the smaller coil, and, while this is passing, it is suddenly passed into the centre of the larger coil, whereupon the galvanometer is found to indicate an inverse current in the latter. Conversely, when the smaller coil is withdrawn, a direct current in the larger coil is indicated.

Faraday has proved experimentally that the insertion of any dielectric, or of any conductor which is not a strongly magnetic body between the primary and secondary coils

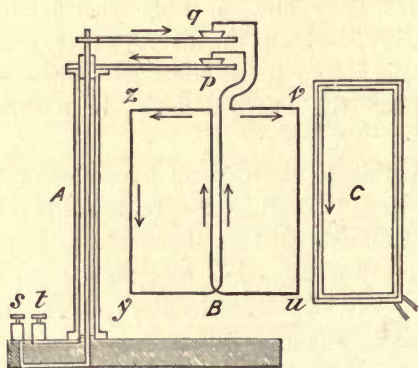


Fig. 7.

does not produce any ultimate diminution of the force of induction.

Leaving, as we have said, the consideration of (c) for the present, we will next consider the action of currents on each other, in producing movements in the conductors which carry them.

The science of electro-dynamics was founded by Ampère, and the following is the description of an arrangement which is essentially that first devised by him for rendering a conductor movable without interruption of the current conveyed by it, and by means of which he demonstrated the mutual attraction and repulsion of parallel currents.

A (Fig. 7) is an upright consisting of a tube in good metallic connection with one of the binding screws *t*, and with a little cup *p*, containing a drop of mercury. A stout wire passes up the centre of the tube, and is insulated from it, but in metallic connection with the screw *s* and the cup *q*. *B* is a light conductor,* consisting of two parallelograms of wire, in which the current circulates in opposite directions, the object of which is to eliminate the magnetic action of the earth. The conductor is hung in the cups *p* and *q*, so as to be easily movable about a vertical axis. *C* is a frame on which several turns of wire are wound, so that, when a current is passed through, we have a number of parallel conductors, all of which act in the same way on the vertical branch *uv* of the movable conductor. Owing to the opposite directions of the currents in the tube and the wire inside it, there is no action on *yz* due to that part of the apparatus, and therefore the action of *C* on *uv* is uninterfered with.

If, as shown in the diagram, the current *vu* is in the same direction as the parallel multiple current in *C*, the movable conductor *vu* is attracted by *C*; if, on the other hand, the parallel currents are in opposite directions, there is repulsion.

The action of straight conductors, which make an angle with each other, may be shown by means of the conductor *D*, represented in Fig. 8, which may be fitted to the stand shown in Fig. 7. In this arrangement the tendency of the suspended circuit is always to place itself so that the current in *lm* shall be parallel to and *in the same direction* as the current in *E*.

The following explanation of the attraction subsisting with the arrangement shown in Fig. 7 is suggested.

When unmixed ether is *stationary* upon the surface of a conductor, as in statical electrification, ether radiation must

* Aluminium is often used.

ordinarily take place in a direction normal to the surface of the conductor, but when the ether is in motion in an electric current, particles radiated will pass out obliquely, partaking of the direction of flow of the stream of ether moving in the conductor, from which the radiation occurs.

It follows that when two parallel similar currents are near together, *if the two currents have the same direction* the radiation of positive ether from either one of them towards the other will occur in a precisely opposite direction to the radiation of negative ether from the latter towards the former, while the radiations of *similar ether*

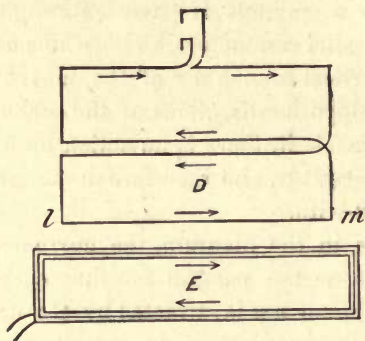


Fig. 8.

from each of the two conductors towards the other will meet at some angle which will be an acute angle if the radiated ether particles have a greater velocity in the direction of the current than normal to it.

And it is suggested that the attraction observed between such currents is due to the attractive force arising from the drawing together, through symmetrical intermixture, of the two kinds of ether moving in opposite directions, being greater than the repulsive force due to the meeting of similar ethers at an angle.

The very similar explanation of the repulsion observed when two parallel currents have opposite directions, is that,

as in this case *similar ethers* radiating from each of the two parallel conductors towards the other will have precisely opposite directions, while dissimilar ethers meet at an angle, the meeting of the similar ethers produces a repulsive force greater than the attractive force due to the drawing together, through symmetrical intermixture, of the dissimilar ethers from the two currents. Kindred arguments to those just given, account for the further elementary law established by Ampère, that currents whose directions are inclined to each other at any angle attract each other if they both flow towards the vertex of the angle, or if they both flow from it, and repel each other if one of them flows towards the angle, and the other from it.

In cases where the attraction and repulsion of one current on another can be expressed as the tendency of a suspended circuit capable of rotation to place itself so that the current in it is in the same direction as a current in a conductor brought near to it, an explanation may be stated in the following more simple form.

Since each of the ethers of a given current, according to our arguments, imparts motion to similar ether lying in space near the conductor carrying it, the motions of the current will be transmitted through space, and either facilitate or retard the ether motions in a second circuit brought near to it, according as the direction of the second current is the same or opposite to that of the first.

Consequently, if the conductor carrying the second current be free to rotate, it will place itself so that its current shall experience the least possible resistance, that is, so that this second current shall be in the same direction as the first.

The relation between the induction of currents by the relative movement of two circuits (treated p. 161), and the mechanical action of currents on each other in producing

movements of the conductors, is well expressed by the following law first enunciated by Lenz, a Russian philosopher. The currents induced by the relative movement of two circuits, are always in such directions as to produce mechanical forces—*i.e.*, either attraction or repulsion as the case may be—tending to oppose the movement.

Assisted by these conclusions we shall, in the next chapter, endeavour to arrive at a theory of magnetism.

CHAPTER XV.

MAGNETISM. DIAMAGNETISM.

WE shall in this chapter endeavour to show that the remarkable properties possessed by a magnet of attracting some bodies—pre-eminently of attracting iron—and of turning when freely suspended, so that a certain direction in the magnet assumes a fixed position relative to the geographical meridian, can be regarded as the result of interaction between the unimolecular ethers and certain kinds of molecular matter.

A theory of the nature of the magnetic condition has to be consistent with the following facts :—

Magnets are bipolar.

Either pole attracts certain other unmagnetized bodies, pre-eminently iron.

Dissimilar poles of two magnets attract ; similar poles repel one another.

The degree of attraction exercised on iron by a magnet, is very different at different parts of the surface, so that when a bar-magnet is plunged in iron filings, the filings hang thickly to the ends, and leave the middle bare, unless the magnet is very thick in proportion to its length.

Like electrified bodies, magnetized bodies exhibit the greatest magnetic force at points and edges.

If a bipolar magnet is broken into pieces, every piece is found to be a complete magnet with poles of its own.

When a piece of unmagnetized iron or steel is brought near to, or in contact with a magnet, it becomes itself for

the time a magnet, behaving just as a magnet in its own right would do,* a fact exemplified when a magnet is plunged in iron filings, the bulk of the filings which are taken up not having personal contact with the magnet, but only with other filings. The fact that bars of iron, such as fireirons for example, display slight magnetization whose polarity depends on their position relatively to the earth, is therefore one evidence that the earth has magnetic properties sufficient to induce weak magnetization in bodies composed of iron.

A bar of soft iron, a poker for instance, magnetized by induction in the way just referred to, and whose upper end thus attracts the north-seeking pole of a magnet, when its position is reversed, so that the upper end becomes the lower, does not sometimes immediately experience a reversal of its polarity, but, *if the bar is tapped, the change at once takes place.*

We have also the allied fact that jarring a bar under magnetizing force causes increase of magnetization.

There is no such transfer of magnetism by conduction, as there is of electricity.

Small magnets have, in proportion to their size, greater lifting power, or portative force, than larger ones ; that is to say, the same quantity of iron liberates more force when in the shape of small magnets, than when in the shape of one continuous magnet. Hence it has been found advantageous to construct compound magnets, consisting of a number of thin bars laid side by side, with their similar poles all pointing the same way.

When a bar of iron is magnetized longitudinally, it

* The distinction between a permanent magnet and a magnet which has temporarily become such by induction is, that the former is attracted only when its appropriate pole is submitted to a given magnetic pole, while the latter is always attracted by either pole of a magnet.

acquires a slight increase of length, compensated however by transverse contraction, so that its volume undergoes no change.

If, however, the iron is subjected to longitudinal traction the magnetic extension is found to be less, and in the case of thin wires under considerable tension magnetization causes diminution of length.

By continually, day after day, adding fresh weights to a magnet it may be made to sustain a much greater load than it would support if applied all at the same time, but if the keeper be torn away this additional power is lost, and only the ordinary power remains.

A magnet employed to magnetize another body gains strength by the process.

Strong currents of electricity, such as traverse the earth's surface during thunderstorms, frequently reverse the polarity of the small magnets called magnetic needles.

If a freely suspended magnetic needle be used to explore the magnetic conditions subsisting around a bar magnet placed in a horizontal position, it is found that when the centre of the magnetic needle is held over the centre of the bar the needle takes a position also horizontal, parallel to that of the bar, but with a reverse situation of its poles. As from this position the centre of the needle is carried along towards one extremity of the bar magnet, the end of the needle towards that extremity is depressed, and the needle dips. This effect is in many cases partly due to the increase of *attractive* force exercised by the pole which is approached, as compared with that receded from, but in the case of a bar but feebly magnetized, where the attraction is scarcely appreciable, it is still observable.*

* The directions of the lines indicated when a small linear magnetic needle is placed in a variety of positions in a magnetic field are beautifully shown by the well-known experiment of placing

The same effect upon a magnetized needle is produced by the earth's magnetism, which is known by experiment to exercise only a directive influence, and not to exercise attraction.* Thus the "dip" of a magnetic needle increases from zero near the equator, where the needle sets parallel to the axis of the earth, to 90° at the magnetic poles, the needle at these poles setting vertical to the horizon. The angle of dip or inclination to the horizon at Greenwich is about 67° .

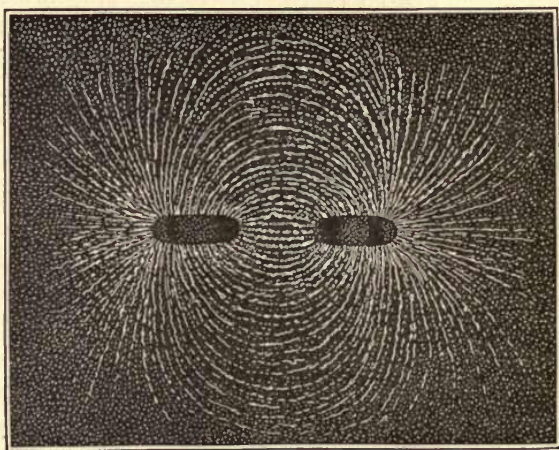


Fig. 9.

The only substance found capable of receiving any very appreciable magnetization is iron, and this is the

a sheet of rough card, or paper, longitudinally upon a magnet, and sifting wrought iron filings over it, the filings, when the paper is gently tapped to liberate them from the effect of friction, arranging themselves to produce a system of curves, such as is depicted in the accompanying diagram (Fig. 9).

* By the simple experiment of suspending a magnetized needle by a long fine thread, and observing that the thread hangs vertical, it has been proved that the magnetic influence of the earth on the needle does not produce translation, but is merely directive.

only substance which is very appreciably attracted by magnets.

Steel, while under the influence of a magnet, exhibits much weaker effects than ordinary iron, and it is much more difficult to magnetize, and does not, moreover, admit of being so highly magnetized; on the other hand it retains a measure of magnetization after the influencing magnet is withdrawn.

Finally—and this is what gives the key to the theory of the nature of the magnetic condition which we have to submit—we have the production of magnetic phenomena with the solenoid invented by Ampère.

This ingenious instrument consists, substantially, of a wire bent into such a shape as to consist of a number of equal circular rings united to each other by straight portions, the relative position of the rings being such that they all lie on transverse sections of the same cylindrical surface, and the object being, by sending a current through the system, to obtain a number of circular currents investing a cylindrical surface and all travelling in the same direction. The effect of the currents in the straight portions, parallel to the axis of the cylinder, which connect the rings, is destroyed by carrying the ends of the wire back until they nearly meet in the middle of the solenoid, so that each straight portion carrying a current in one direction has set against it a corresponding straight portion carrying a current in the opposite direction.

If a solenoid is freely suspended on an Ampère's stand, when it is traversed by an electric current, it takes the position a magnetic needle would do. Further, if an element of a solenoid, that is a simple plane circuit, be nicely balanced about an axis through its centre of gravity, and placed so that it can turn freely in the plane of the magnetic meridian, the passage of a current causes it to set its plane perpendicular to the direction of a dipping

magnetic needle. Lastly, the similar poles of two solenoids repel, and the unlike poles attract each other when the solenoids are brought end to end ; and if an ordinary magnet and a solenoid are used together we have similar effects.

The theory of the nature of the magnetic condition which we have to offer is that a body in this condition has currents of the two ethers eddying round its opposite extremes, unmixed positive ether rotating in one direction, unmixed negative ether in the other around both ends of the axis of the magnet, similar ethers following the same direction at both ends of the magnet.

As to how this state of things accounts for the attraction which is exhibited by a magnet for a piece of iron, we suppose (1) that the opposite rotations of the two unmixed ethers at the ends of the magnet are communicated to the similar ethers in the medium around the magnet, and that when an unmagnetized piece of iron is brought near the magnet these motions are passed on to the ethers present among its molecules, and produce similar rotations of the unmixed ethers found from time to time in the hitherto unmagnetized iron (see p. 67) similar to those taking place in the magnet, and in the same direction, so that the piece of iron becomes a magnet with poles similarly placed to those of the inducing magnet, in other words has its direction of magnetization the same as though it were continuous with, and formed part of this magnet.* And (2) that the faces of the magnet and the piece of iron which are turned towards one another, being thus traversed by ether currents in the

* When the body in which magnetism is induced and the magnet lie side by side, the respective rotating currents therefore have opposite directions, like those in the two arms of a horseshoe magnet, the similar ethers as they revolve, to make a rough comparison, moving in harmony like the cogs on two machine wheels that are running together.

same direction, attraction ensues according to the discovery made by Ampère above referred to, and which we have already endeavoured to explain (p. 165).

The case of a magnet is thus supposed to be almost precisely similar to that of the solenoid, the principal difference being that in the solenoid the currents are distributed from end to end, but are broken up owing to the conducting material being separated into sections by non-conducting air, while in the magnet the currents are found only towards the two ends, but are broad and united owing to the continuity of the conducting material they are traversing.

M. Stroh has shown that at the point of contact of two metals carrying strong electric currents a similar cohesion to that of magnets in contact occurs.

We must conclude that there is a possibility of the existence of opposite rotations of the same ether in different sections of the same bar, from the fact that it sometimes happens, either from some peculiarity in the structure of a bar, or from some irregularity in the magnetizing process, that a magnet has what are called consequent points, at which reversals of the direction of magnetization take place, the magnet thus resembling a system of several magnets placed end to end with similar poles in contact.

Such a theory as the above is evidently in harmony with most of the above facts respecting magnets, allowing, as it does, the arguments offered in explanation of the properties of the solenoid to be extended to the case of a magnet.

The fact that magnetized bodies resemble electrified bodies in exhibiting the greatest force at points and edges may perhaps be connected with their both exercising their influence by means of ethers radiated through a non-conducting medium, and consequently being alike affected by the degree of readiness with which radiation takes place (see p. 81). And in connection with this the recent

observation may be referred to, that magnetizing force, like electrical force, takes time to develop, the time occupied being, however, very small.*

From the readiness with which iron passes into the magnetic state, we suppose that in the case of this substance a very slight inciting force is needed to make the unmixed ethers from time to time found among its molecules execute the movements to which we have attributed the existence of the magnetic condition ; and this supposition is countenanced by the fact alluded to, of the reversal of the polarity of magnetic needles by the passage of currents of electricity.

The facts alluded to, that ordinarily magnetization produces elongation of the mass magnetized, but that wires under considerable strain contract when magnetized, seem to indicate (1) that a certain stretching of the molecular framework (p. 40) of the iron in the direction perpendicular to the plane of rotation of the rotating currents of unmixed ethers ordinarily facilitates the motions of these ethers through the interstices within the mass, and is consequently caused by these motions ; and, consistently with this (2), that if the molecular framework of the iron is stretched by tension there is, if the stretching is not so great as would be produced by the currents of magnetization, less for these currents to accomplish to bring the molecular framework to the disposition most favourable to the ether motions ; and further, that *if the tension is sufficient to cause a greater distortion than this disposition involves*, the effect of the currents of magnetization is to reduce the distortion so as to bring the molecular framework nearer to this particular disposition.

This view is supported by the fact that when a bar, subject to a magnetizing force in the direction of its length, is stretched in the same direction, its temporary

* "Enc. Brit.," Art. "Magnetism," p. 273.

magnetization increases. Also by the fact that if a bar, under the influence of a longitudinal magnetizing force, is twisted, the magnetization increases with small twists, but decreases again with large twists. The first effect of twisting is usually to increase the magnetization ; but, if the bar be jarred beforehand, the twist at once causes a decrease, which disappears when the twist ceases.* The twisting of the bar, like the twisting of a rope, evidently causes a squeezing together of the particles transversely.

The fact that a magnet will sustain a greater load if weighted by slow degrees, and not all at once, suggests a comparison with the preparedness of the voltaic arc, above alluded to (p. 68), and may probably be due to a gradual strengthening of the rotating currents of ether of the magnetic condition as they continue in the same paths. The fact that the additional power is lost when the keeper is torn away seems to indicate that the change is one which merely affects the ethers of the currents and does not extend to the molecular matter among which they circulate.

That some slight permanent molecular change is effected in a mass by magnetization appears, however, to be indicated by the fact that, although the mere continuance of the magnetizing force does not increase the resulting permanent magnetization, the repetition of its application will.†

The magnetic properties of the earth we suppose to be due to a general rapid rotation around it, in all latitudes, of the ethers from time to time found unmixed near or at its surface, unmixed positive ether moving in the direction east to west, unmixed negative ether in the direction west to east.

The following explanation may be suggested of the

* "Enc. Brit.," Art. "Magnetism," pp. 269, 270.

† "Enc. Brit.," Art. "Magnetism," p. 257.

directive influence exerted on a magnetic needle, or on a solenoid by the earth's magnetism ; it is on much the same lines as the explanation previously suggested of the fact that a suspended circuit capable of rotation, tends to place itself so that the current in it is in the same direction as a current in a conductor brought near to it (see p. 167).

Confining our attention to the narrow zone, or element, of a magnetic needle lying in a transverse section of it, we see that the revolving ring of each kind of ether found in the plane of such an element will be acted on by the motions of *the same* kind of ether taking place in the earth's atmosphere, which are arising from the magnetic condition of the earth ; and that the portion of the current of each ether in the element whose direction coincides with, or is nearest to that followed by the same ether in the earth's atmosphere at the place will be assisted by these motions, while the portion of the current opposite to this on the other side of the element will be opposed by them.

Now, on the one hand, we may conclude that if, as already argued, there is a gradation of density of the ether above the earth's surface, the ethers thus moving in the earth's atmosphere will have the greatest hold on the ethers moving in the element *on the side of the latter nearest to the earth's centre*, because the ether density, and therefore the cohesion, will be greatest on this side ; but, on the other hand, the velocity of the ether movement around the earth will be greatest *furthest from* the earth's axis, and will therefore, so far as it only is concerned, produce most effect on the ether's moving in the element *on the side of it furthest from this axis*.

The effect of the currents of the earth's magnetism on a magnetic element which is perfectly free to move is, it is suggested, partly traceable to one effect, partly to the other. When a magnet placed at the equator sets horizontal with the pole corresponding to the south pole of the earth

turned towards the north, we suppose that it takes this position, in which the portion of the current in the needle *nearest to the earth* has the same direction as the earth current, because the latter has the greatest effect nearest the earth where the ether density is greatest. When, on the other hand, a magnet placed near the north or south pole sets vertically with its poles placed similarly to the poles of the earth, we suppose that it takes this position, in which the portion of the current in the needle furthest from the earth's axis is in the same direction as the earth current, because the earth current has the greatest velocity furthest from the earth's axis; the ether density, be it observed, being in this case constant throughout each transverse element of the magnet. Cases of dip intermediate between these extremes we trace partly to each of the above, *i.e.*, partly to differences in density, partly to differences in velocity of the ethers of the atmosphere moving past each magnetic element, the effect of the gradation of density predominating towards the equator, that of the differences of velocity towards the poles.

Next, as to the processes by which magnetization is produced. If, as above suggested, the magnetic condition is due to the existence of broad electric currents rotating about the magnetized body, we should expect the processes which produce magnetization to appear, in the light of our arguments, as so many methods of imparting rotation to the unmixed ethers.

Facts are in harmony with this expectation; thus in the case of electro-magnets, some of which are capable of sustaining a load of more than a ton, we have a cylindrical bar of iron which has a coil of insulated wire wrapped round it powerfully magnetized when a current is sent through the coil of wire. Stout copper wire is generally employed, and the direction of winding on the wire must be the same from end to end. The south-seeking pole,

that is, the pole corresponding with the north pole of the earth, is found to be that end of the bar at which, to the eye of an observer looking towards it, the current is passing round the magnet in the direction of watch hands. We suppose that the moving ethers of the current in the wire communicate motion to the similar ethers, to which they are attached by some degree of cohesion, present in the medium surrounding the wire, and through these to the ethers in the neighbouring iron bar.

The explanation how the feeble motive power thus indicated may suffice to set up the rapid vigorous ether-motions which we have suggested constitute magnetization is precisely that we have already offered to account for the setting up of the sensible currents of galvanic circuits by certain supposed feeble movements of the ethers (see p. 129).

Again, one method of permanently magnetizing steel consists in drawing a bar of steel over the pole of a fixed electro-magnet, *taking care that the same end of the bar is always the last to leave the magnet*; the direction of magnetization is then such that this end is the pole opposite in character to the pole of the electro-magnet. Either pole of the electro-magnet can be used, but, in accordance with the condition just stated, the direction of rubbing must be reversed if a change is made from one pole to the other. A second method is to make a few turns of a wire conductor around a bar to be magnetized, and to move the coil along the bar while the current is passing. In both cases it is evident that, according to our theory, motion is continually imparted to one unmixed ether of the body being magnetized in one direction, to the other ether in the opposite direction, as in the above case of an electro-magnet.

Finally, a probable cause of the production of ether-motions in the earth, such as we have supposed constitute its magnetism, may be indicated as follows.

The molecular matter of the earth, having by hypothesis some cohesion with the unimolecular ethers with which it is in contact, must, it is evident, to some extent carry these ethers round with it as it rotates from west to east ; but the cohesion is, by hypothesis, *not the same for both the ethers*, and, if we suppose the more readily compressible, or positive ether to have the less density of the two under the conditions prevailing, this ether will have less cohesion, or adhesion, to the molecular matter of the earth than will the less readily compressible or negative ether.

Now the various waves continually passing through the two unimolecular ethers will be often found driving some of the ether particles in a contrary direction to the course from west to east maintained by the earth's surface, and if a greater cohesion binds the less readily compressible ether to the earth than that subsisting between the earth and the more readily compressible ether, the less readily compressible or negative ether will more completely in its general motion follow the motion of the earth than will the more readily compressible or positive ether ; and therefore, we must look for a motion from west to east of the negative ether with respect to the positive ether. As in the other cases of the production of ether currents (p. 129), we suppose that this induces the motions of re-intermixture of unmixed ethers which are occurring to be chiefly in the one direction, and consequently produces opposite currents of the two ethers in this one direction.

We have thus indicated a probable cause adequate to produce two broad ether currents round the earth in opposite directions such as we have supposed constitute its magnetic state.

The explanation just given is on much the same lines as that we have offered of the production of electricity by friction (see p. 76).

As experimental proof of the power of a simple rotation

to set up electrical conditions such as we have described, it may be mentioned that Professor Lemström, of Helsingfors, has recently discovered that a ring of insulating material when rotated about its axis of symmetry with a high velocity acts like a galvanic circuit, and produces a magnetic field in the space within it.*

The fact of the increase of magnetization of a bar when it is jarred during the process, which is above alluded to, reminds us of Hopkinson's observation that tapping the dielectric of an electric condenser facilitates the liberation of the residual discharge (p. 120); it will, according to the above theories, have a similar origin.

In reference to the significant fact that iron is both the only substance found capable of receiving any appreciable magnetization and the only substance appreciably attracted by magnets, we may suppose that for considerable ether motions of the peculiar nature to which we have attributed the magnetic condition to take place, the proportions of the two unmixed ethers present must bear some peculiar relation, perhaps that of equality, and that in the case of soft iron it so happens that the relative quantities of the ethers liberated by molecule destruction are such as to give this relation.

Such a supposition appears to be favoured by the fact of the demagnetization of magnets by heat, for we have already concluded that from the same group of molecules the two ethers are sometimes emitted in different proportions according to the temperature of the mass (p. 131). The sensitiveness of magnets to changes of temperature renders it necessary for magnetic observatories to be kept at a nearly uniform temperature.

The different behaviour of soft iron, and steel under magnetization may, it is suggested, be attributed to difference of conductivity, for we may suppose that paths for

* *Nature*, No. 552, p. 89.

the moving ethers are less readily opened up in the inferior conductor, but that in this inferior conductor the motions in these paths are less interfered with by irregular motions of the ethers after the paths are once opened.*

The difference between magnetic north and true north, which is called magnetic declination, which varies greatly at different places, and besides, continually undergoes gradual change from year to year, as well as displaying smaller changes, we attribute to the effects on the earth's magnetism of irregularities of ether distribution which we suppose are existing at the earth's surface. (The subject is referred to again under Meteorology.)

The facts stated in the text books, that *magnetic potential* can be defined in the same way as electric potential, and that *magnetic lines of force* possess the same properties as electrical lines of force, are evidently consonant with the unity of origin we have attributed to electric and magnetic phenomena.

Close observation has revealed that feeble powers of attraction and repulsion are manifested by crystals† of several kinds of minerals, and many artificial salts, when heated or cooled; and the Abbé Haüy discovered that the attracting power of tourmaline, topaz, and other minerals decreases rapidly from the summits or poles, which in many cases exceed two in number, towards the middle of the crystal, where it is imperceptible; that it is, in fact, distinguished by polarity, and, moreover, that any fragment of crystal, however small, displays the same polarity.

Probably these effects are rather electrical than magnetic, and to be referred to the liberation of small quantities of unmixed ethers by molecule destruction, and to some differences in the readiness of ether emission in different

* In the soft iron core of an electro-magnet nearly all the magnetization disappears when the current in the coil is stopped, but not quite all; there is a small amount of residual magnetism.

† Consequently called pyro-electric crystals.

directions due to the peculiar symmetrical arrangement of the molecular matter forming the crystals ; this suggestion will be better understood when we have considered the subject of crystallization.

Diamagnetism.

It was first shown by Faraday in 1845, that all, or nearly all substances in nature are susceptible of magnetic influence. He suspended various bodies before one of the poles of a powerful electro-magnet, and found that while some bodies were attracted, other bodies were repelled, and in this way, established that, so far as magnetic influence is concerned, the various natural substances may be regarded as divided into two classes. (1) Those substances which are attracted by either pole of an electro-magnet, and which are called magnetic or paramagnetic bodies ; (2) Those which are, under the same conditions, repelled, and which are called diamagnetic bodies. By far the greater number of bodies belong to the second of these classes, but the repulsion which they manifest is incomparably feebler than the attraction exhibited by some of the paramagnetic bodies.

The following facts respecting diamagnetic bodies have to be considered in seeking for a theory of the origin of their diamagnetic property.

Diamagnetic substances are, as stated, repelled by either pole of a magnet.

If a bar of any such substance is freely suspended between the two poles of an electro-magnet, it sets equatorially, that is with its length at right angles to the line joining the poles. This rule, however, requires some modification where the body experimented with is more susceptible of magnetic influence in some direction or directions than in others, as is the case with many crystals and with bodies whose particles present different degrees

of proximity in different directions—*e.g.*, stratified or fibrous bodies.*

Becquerel, Reich, and Tyndall have established, in reference to diamagnetic repulsion, that, in diamagnetic bodies, as in paramagnetic bodies destitute of *coercive force*, the strength of the magnetic condition excited by the presence of a magnet rises and falls with, and is proportioned to, the strength of the exciting magnet. Thus Tyndall has found in experimenting with two balls of bismuth placed in the opposite scales of a delicate torsion balance between the poles of an electro-magnet, that the force of repulsion subsisting between the magnetic poles and the bismuth balls varies approximately as the square of the intensity of the current around the magnet, showing that when the magnet varies in a particular ratio, the intensity of the magnetic condition of the bismuth balls varies in the same ratio ; an observation proving that, like the attraction of paramagnetic bodies, the repulsion of diamagnetic bodies by a magnet depends on a quality induced in them by the presence of the magnet.

In reference to the same property of repulsion, Reich and Tyndall have both shown that although the two poles of a magnet, each operating alone, will repel a diamagnetic body, when two dissimilar poles act conjointly at the same point, there is no repulsion ; thus establishing that the condition induced by the presence of one pole of a magnet is not identical with that induced by the opposite pole, but is, as it were, the converse of it.

Tyndall has found that in approaching a pole of a

* There are, too, cases in which, owing to the diamagnetic or paramagnetic property of the medium surrounding the body experimented with being more marked than the same property of this body, the latter takes a subordinate position opposite to that it would take if this were not the case, being that position which best allows of interaction between the medium and the magnet.

magnet, the attraction of a magnetic particle mounts much more speedily than does the repulsion of a diamagnetic ball.

The same indefatigable observer has used cores of bismuth to compare with cores of iron, freely suspending both between the poles of powerful magnets, and at the same time exciting the cores by electric coils, within which they are suspended. He has found that, invariably, the polarity of the bismuth bars is, in similar arrangements, the converse of the polarity of the iron bars.

The theory of the nature of the diamagnetic property found in some bodies, which we have to offer, is that when a magnet is brought near one of these bodies, the rotating ether currents in the magnet, which we have suggested are the source of its magnetism, produce for the time being a magnetic state in the diamagnetic body, similar in kind to that they would produce in a paramagnetic substance, *but that the ether rotations set up, instead of having the same directions as those in the magnet, as would be the case in a paramagnetic substance, have opposite directions.*

This involves the development opposite that pole of the magnet which is presented of a similar pole in the diamagnetic body, instead of a pole of the opposite kind, and the repulsion observed has the same explanation as the repulsion of similar poles of two magnets.

As in the cases of induced magnetism, and the production of magnetization by sending a current through a coil, we suppose that the currents of ether set up in the diamagnetic body are due to the motions of ethers from time to time found disentangled from one another in this body, as they reintermix, and that the influence from without is merely a directive one.

That the effect produced is, as just supposed, the converse of that produced in paramagnetic substances, we suggest may be due to the molecule destruction proceeding in the diamagnetic body furnishing from time to time an excess of one or other of the two ethers.

CHAPTER XVI.

ELECTRO-MAGNETIC PHENOMENA—PHENOMENA OF
ELECTRIC INDUCTION.

WE will next direct our attention to the electro-magnetic phenomenon of the deflection of a magnetic needle by an electric current, discovered by the Danish philosopher, Ørsted, in 1819 ; a discovery of which such immense application has been made in telegraphy.

Guided by theoretical considerations, Ørsted found that if a magnetic needle be placed in the neighbourhood of an insulated wire carrying an electric current the passage of the current produces a change in direction of the magnetic needle, unless the wire carrying the current has a certain neutral position with respect to the direction of the needle.

The direction in which deflection will take place is ascertained by the following rule :—

Suppose the observer to be looking vertically, either upwards or downwards, at a magnetic needle, and that the wire carrying the current runs horizontally directly between him and the centre of the needle, and that this wire passes vertically with respect to his eyes, *i.e.*, at right angles to the line joining them ; then, when the current is passing *upward* as looked upon by the observer, the deflection of a north-seeking pole will be to the left, and consequently that of a south-seeking pole to the right.

The neutral position referred to is that in which the plane containing a pole of the needle and the current is perpendicular to the length of the needle, the portion of

the supposed rotating ether currents of magnetization which are on the side nearest the linear current having, at the same time, the same directions as the ether currents in the wire.

If our conclusion be accepted that broad ether currents are rotating around every magnet, the direction taken by the positive ether being against watch hands as we look towards the magnet from beyond the north-seeking pole, the law thus stated is deducible in the following manner from the laws discovered by Ampère of the attraction and repulsion exercised by currents on each other.

It is evident that in all cases a portion of the rotating currents on one side of a magnetic pole experiences attraction while a portion on the opposite side experiences repulsion (p. 164). Now a moment's consideration shows us that *when a needle is in the neutral position above referred to the movement of its pole towards the linear current lessens the distance between this current and the portion of the rotating current of the needle furthest from it (i.e., the portion which is experiencing repulsion), more than it lessens the distance between the same linear current and the portion of the rotating current nearest to it (i.e., the portion which is experiencing attraction); and, therefore, it is natural to conclude that in making this movement the pole of the needle will experience a greater rise of repulsion than of attraction. Similarly we conclude that in making a movement from the same position away from the linear current the same pole will experience a greater rise of attraction than of repulsion. Consequently we argue that, if we neglect the effect of the earth's magnetism, a needle capable of turning upon its centre in any direction, and which is acted on by a linear current, will, if it is not already close to the neutral position above described, turn towards this neutral position.*

It is evident that when a magnetic needle is *capable of*

moving only in one plane the current in the wire operates in the case of both poles to turn the needle in the same direction, so that the force of deflection acting on one pole is added to the force of deflection acting on the other.

The fact that the degree of deflection reveals the strength of the current which produces it supplies the principle employed in the construction of the various kinds of galvanometers used to measure the strength of electric currents, but as our task is confined to tracing the phenomena of electricity considered as a function of the unmixed ethers, we shall not consider the different forms of these instruments.

Induction of Currents by Magnets.

It will be remembered that the case of induction of a current by the action of a magnet was deferred until we should have obtained an insight into the subject of magnetism (see p. 161); we are now in a position to deal with it.

When a magnet is magnetized or demagnetized in the neighbourhood of a circuit, or approaches or recedes from the circuit, the effect is the same as if an equivalent current approached or receded from the circuit. For example imagine a small circular circuit placed horizontally, and a vertical bar magnet lowered in the axis of the circuit with its north pole pointing down upon the circuit, the magnet may be replaced by a series of co-axial circular currents, and the motion will induce a momentary current passing round the circuit against the hands of a watch.*

The very terms of this description, read in the light of our conclusion that magnetism is due to the existence of broad ether currents revolving around the magnet (p. 174), completely suffice to show the applicability of the reasoning

* Taken from "Enc. Brit.," Art. "Electricity," p. 75.

which has already been given with regard to the cases marked (a) and (b) (see p. 161) to the case now before us. The fact that this is so furnishes important corroboration of our conclusion that revolving ether currents are present in magnets.

The experiment may be varied by placing a soft iron bar in the cavity of the coil, and moving the pole of a magnet towards or from the end of this bar, thus producing an increase or diminution of the induced magnetization of the bar (see p. 169). The intensity of the effects in this case is very striking.

The entirely mechanical nature of ether currents is brought out by the fact that the sudden making or breaking of a current produces a development of electromotive force not attained during the steady continuance of the current, the exhibition of electromotive force being, according to our arguments, evidence of the separation of the two ethers. This is illustrated in various ways.

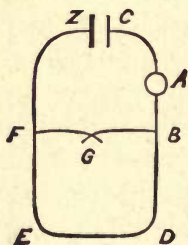


Fig. 10.

One of the simplest is that by which Mr. Jenkin has shown that, although it is impossible, with a short circuit of wire and a single battery cell, for an experimenter to obtain a shock by making and breaking contact, he may obtain a very powerful shock if the coil of an electro-magnet is included in the circuit. Thus:—Let $z\ c$ (Fig. 10) be a battery of a single cell, $C\ A\ B\ D\ E\ F$ a circuit, with a cross branch $B\ F$, in which at G the human body, etc., may be inserted; contacts can be made and broken at A , very rapidly if need be, by means of a toothed wheel. When $B\ D\ E\ F$ consists of a short single wire, nothing particular is felt at G , but when the coil of an electro-magnet is inserted in $D\ E$,

the patient at G experiences a series of powerful shocks comparable to that obtained from the secondary coil of an inductive apparatus.*

This arrangement was modified by Faraday, who placed a galvanometer at G and observed the increased intensity, and the direction of the electromotive force due to making, and also that due to breaking the current ; he also showed the increase of force at G by its procuring the ignition of platinum wire, and by the production of chemical action.

The development of electromotive force by what is known as Ruhmkorff's induction coil furnishes another illustration. This apparatus, named after its inventor, is constructed as follows :—A comparatively short cylindrical coil of copper wire invests a central core, consisting of a bundle of straight wires of soft iron, which are united at the ends to discs of the same material. Around this coil is wound a greatly longer coil of much finer wire, very carefully insulated. An arrangement is provided by which successive makes and breaks of a current in the smaller coil (called the primary coil) are effected. The result is a rapid succession of instantaneous currents, produced by induction in the larger or secondary coil, flowing alternately in opposite directions, and the great electromotive force of these currents is manifested by the long sparks obtained, the effects exhibited being comparable to those produced by frictional electrical machines.

By way of explanation of these instances of development of electromotive force by the sudden making and breaking of currents, we remark—

1. That if, as we have supposed, an electric current consists in the passage of one kind of ether in one direction in a circuit, and the simultaneous passage of the other kind of ether in the opposite direction ; when such a current is suddenly started, any particular point in the circuit except

* "Enc. Brit.," Art. "Electricity," p. 79.

the middle point will be reached by the flow of one kind of ether *before* it is reached by the flow of the other kind of ether.

2. Similarly, that when such a current is suddenly broken, any particular point in the circuit, except the middle point, will be left by the flow of one kind of ether *before* it is left by the other.

3. That, since potential is measured by the quantity present of one of the ethers in excess of the other, a high potential, positive or negative, as the case may be, will be manifested after the flow of one ether has reached any given point, and before the other ether arrives ; or, in the case of breaking a current, after the flow of one ether has ceased and before the ceasing of the flow of the other.

4. That the time which will elapse after one ether reaches a given point, and before the other arrives will be a function of the length of the circuit ; the longer the circuit, the longer this interval. Consequently, that the longer the circuit the greater the manifestation of electromotive force when the current is started or broken.

The presence of the bundle of iron wires in the centre of the primary coil we may suppose intensifies the effect by increasing the ether density in the neighbourhood of the current.

The alternating discharges from a Ruhmkorff's coil may, according to the above, be compared, by way of rough illustration, to the surging over of water in a shaken vessel, the momentum of the currents causing the two ethers to be alternately jerked out from the mass of ethers in which they are normally present side by side engaged in the process of intermixture, that is in the process of neutralizing each other.

We will close this chapter with a reference to some striking instances of interaction between masses of metal and magnets situated in their neighbourhood.

Of these we may mention first, the action of copper dampers, as they are called, in checking the vibrations of magnetized needles, it being found, when a magnet is suspended over a copper disc, or, better still, in a small cavity inside a mass of copper, that its vibrations are checked by the near presence of the mass of copper, as though it were immersed in a viscous fluid.

A second instance is furnished by one of what are known as Arago's rotations. If a magnet, with its axis horizontal, be suspended over a disc which is rotating upon a vertical axis, the needle tends to rotate in the same direction as the disc, and if the velocity of the disc be sufficient, or if the needle be rendered astatic, the latter will be carried round continuously. The conductivity of the metal of the disc is found to regulate its rotating power.

A third instance is presented by Plucker's experiment with a copper cube. He suspended such a cube by a thread, and set it spinning between the poles of a powerful electro-magnet ; and he then found that on the magnet being excited the rotation of the cube ceased instantaneously.

Lastly, a very similar experiment to this has been made by Foucault, who arranged a flat copper disc between the flat poles of an electro-magnet, so situated as just to allow room for the insertion of the disc between them. The disc being set in motion by a driving gear, he found that when the magnet was excited much more force was requisite to keep up the motion of the disc.

The same explanation of all these examples is here submitted, and is as follows :—

When a magnet is rotating with respect to a neighbouring metallic surface, or when such a surface is rotating with respect to a magnet, in either of the methods above described, it is evident that every point on that part of the metallic surface which is brought into the vicinity of the

magnet by the rotation will be found alternately approaching the magnet, and then, receding from it, as by the rotation it is first brought round opposite to the magnet, and then carried past it.

Now, if we confine our attention to some particular point thus affected, we see that the rotating ether currents of the magnet will by induction set up a local electric current at this point, the ethers of which will move in *opposite directions to the currents in the magnet* as the point *approaches* the magnet, *in the same directions* as the point *recedes from* the magnet. And, therefore, all the points which by rotation are from time to time brought opposite to the magnet will continually experience opposite influences—now an influence tending to produce currents *opposite in direction* to that in the magnet, now an opposite influence to this tending to produce currents in the same direction as that in the magnet ; and, since every current thus induced must be regarded as lasting for some period of time, however short, *these conflicting influences will be co-existent.*

Finally, the greater the velocity of rotation, the more violent the conflicting tendencies thus excited will be.

Therefore, since all change of relative position of particles of the ethers is opposed by the force of cohesion, the reflex action of this force will be to oppose the rotation.*

* When rotation is compelled, in opposition to the restraining influence thus exerted, heat is the result, a fact which is instructive in the light of the conclusion we shall endeavour to establish in a future chapter, that heat is a function of the intermixed ethers (p. 302).

CHAPTER XVII.

THE ELECTRIC LIGHT.

CASUAL mention has been made in the foregoing pages of the light produced by the electric discharge, as in sparks, etc., but no explanation has been offered of the connection between electricity and light. We will not here forestall the arguments found in the subsequent chapters of this treatise, as to the origin of light, but will merely observe that these arguments will go to show that light arises from the destruction of molecules and the explosion of the primary atoms they enclose, and therefore that the production of light must be looked for wherever the accumulation of unmolecular ethers produces a large amount of molecule destruction. As, according to the conclusions reached above, increased symmetrical intermixture takes place, and an accumulation of intermixed unmolecular ethers is produced wherever an electric current traverses a bad conductor, this furnishes us with an explanation of the association of light with electrical discharges.

As to the production of heat by electricity, we shall presently argue that accumulations of intermixed unmolecular ethers are productive of heat.

The most striking instances of the power possessed by electricity of producing light and heat are found in what is known as the electric light.

If two pointed pieces of gas retort carbon are respectively connected with the opposite poles of a powerful

voltaic battery, and then brought together so that the current may pass between them, a continuous light is produced. When the current has begun to pass, the carbons may be separated to some distance without preventing the discharge, the interval between them being occupied by a luminous tract of intense brightness, and excessively high temperature, known as *the voltaic arc*. The light obtained in this way is, in brightness, second only to that of the sun, and the heat is adequate to the fusing, and even the volatilizing of all known substances, even the most refractory.

Reserving further consideration of the origin of the light, let us look at the phenomenon simply as a means of revealing to us some additional facts as to the behaviour of the two ethers in an unimolecular state.

And first we may notice the fact that although the carbon electrodes must be brought together to start the light, the discharge will not be broken afterwards by their separation to a moderate distance. Sir Humphrey Davy, who first observed the phenomenon, obtained a luminous arc four inches in length, and when the discharge occurred in vacuo, an arc of seven inches.

An allied fact to this is that the arc once started has a certain persistence, so that if we break the current for one-twentieth of a second or so, the light will start afresh without our bringing the carbons into contact ; or the light may be started originally while the carbons are separated if a spark from a Leyden jar passes across the interval between them.

The lesson taught by these facts seems to be that already insisted on in the early pages devoted to the present branch of our subject (p. 66), namely the necessity of continuity of one kind of ether that conduction may take place ; the natural explanation of the above being that the passage of an unimixed ether arranges, for the moment, the ethers in

the voltaic arc in a manner favourable to continuous conduction, procuring continuity of each kind of ether between the poles.

It is interesting to notice, in reference to the supposition that the power of a body of the unimolecular ethers to procure atom expansion and molecule destruction is the source of the light of the voltaic arc, that we have ocular testimony that a body of electricity has the power of producing the explosion of matter ; for when, with the aid of a lens, an image of the incandescent carbons is thrown upon a screen, and this image is narrowly observed, incandescent particles are seen to be traversing the length of the arc, sometimes in one direction, sometimes in the other ; the prevailing direction being, however, that of the positive current, and the result of the dislodgment of some particles of carbon being seen in the alteration of shape of the carbons, the positive carbon becoming concave, and the negative remaining pointed ; the latter, indeed, having added to it some small portions of the substance carried away from the former in part mitigation of the waste it is undergoing. Several experiments have, moreover, been made to prove that there is a transfer of molecular matter in the direction of the current.

That the positive ether of the current surpasses the negative in destroying power may, perhaps, be due to the greater readiness of compression of the former causing the fluctuations of pressure which are occurring (p. 25) to reach a lower minimum pressure where this unimolecular ether is present.*

We conclude that there is an accumulation of the two ethers *in their unmixed state* in the voltaic arc, from the fact of a considerable return current discovering itself

* It will, however, be argued hereafter that the positive ether, *when in small quantities*, procures combustion through the intervention of the negative ether.

when a galvanometer is substituted for the battery by which the arc was formed.

As we should expect from our theory of its origin, light is a constant companion of the electric discharge when this discharge is interrupted in any way, and many other instructive facts respecting the two ethers may be learnt from the feebler luminous effects which they produce when the discharge is not so intense as in the case of an electric lamp. Perhaps one of the most interesting of these effects is the rotation of the luminous streaks of a discharge occurring through a rarefied gas, produced by bringing the ether currents passing through the gas under the influence of a magnet. The method of accomplishing this well-known experiment is as follows :—

A soft iron rod is fitted so as to protrude into the interior of an exhausted vessel, and is coated with an insulating substance to prevent discharge between it and a metallic ring which surrounds it near its place of contact with the interior surface of the vessel. Opposite the soft iron rod, and projecting towards it, is fitted a wire which forms one of the terminals of a voltaic battery, the ring which invests the bar forming the other terminal. The result of this arrangement is that a discharge will ordinarily occur with comparatively equal facility between any point of the circumference of the ring and the opposite pointed wire terminal.

While a discharge is occurring, the apparatus is applied to one pole of an electro-magnet, so that the bar becomes magnetized by induction ; the luminous discharge then rotates about the bar.

This beautiful experiment furnishes palpable evidence of a rotatory movement in the magnetic field, and is explained in harmony with our previous conclusions, if we suppose that the luminous matter of the arc is more strongly attached by cohesion to one of the two ethers

than to the other, and that this ether present in the arc partakes, as we have already supposed (p. 174), of the movements of the same ether occurring in the magnet, and imparts some of its motion to the luminous matter.

Faraday's experiment of the rotation of the plane of polarization by magnetic influence, and an experiment made by Mr. Kerr, of Glasgow, of the effect on polarized light exerted by a piece of glass when subject to strong electric force, are referred to under the heading of Light.

Other motions of luminous discharges may be produced by magnetic influence, all of which are consistent with the conclusions which have been arrived at in this volume as to the nature of electric currents and of magnetism. The fact that the path of the luminous discharge can be diverted by a blast of air is an additional proof of the material nature of the electricities traversing the voltaic arc.

LIGHT.

CHAPTER XVIII.

THEORY OF THE NATURE OF ETHER WAVES.

IN the next place we propose to consider the phenomenon of light as it exists apart from sensation, leaving for a subsequent place the inquiry into the nature and limitations of the apparatus of vision.

Light is, it is suggested, due to wave motions of the hypothetic ethers of a nature we will now endeavour to describe.

The two fundamental properties attributed to the ethers—elasticity of bulk and viscosity—must to *some extent* invest them with the property conspicuous in solids—*elasticity of form*. For, if we suppose some *small* wave movement to traverse the interior of a mass of ether, the existence of any viscosity, however slight, will operate to lessen the amount of separation of particle from particle of particles previously in contact, and, as a consequence, the displaced ether particles *will tend to return to their original relative disposition with respect to one another* when, owing to their elasticity of bulk, they recover uniformity of density or distribution after the wave movement has passed.

And we may conceive of wave motions *on so small a scale* that, *when one kind of ether only is present*, units of ether such as we have called primary atoms experience no appreciable permanent change of their relative disposition *as the result of these motions*.

It is suggested that the motions of the ether waves which propagate light are of this minute description.

The theory we have to submit of the origin of these, and of other waves of a similar character not competent to produce the sensation of light, but revealing themselves by their heat-producing or chemical effects, *is that the impulses which start them are produced by explosions of primary atoms.*

A sketch of the supposed method of production of the waves, and of their supposed nature follows.

At places where the occurrence of violent ether movements produces very great destruction of primary molecules, and, consequently, very numerous explosions of the enclosed atoms (p. 20), it is suggested that an effect analogous to electrical conduction, depending like it *on ether continuity*,* causes the explosion of any given atom to produce the explosion of *similar* atoms near to it, rather than of atoms of other kinds;† the theory being that where contiguous atoms of the same kind, subject to similar conditions, are exposed to the same ether movement, *they have the same rate of expansion and contraction, and expand and contract together*; and that, as a consequence of this synchronism, the passage of one of these atoms beyond the critical point at which the surrounding pressures are competent to make it contract again (p. 31) tends to carry other similar contiguous atoms also beyond the critical point.

Further it is evident that, as a direct result of the pressure it produces, the explosion of any atom has another effect of an opposite nature to that just referred to, that it exercises a conservative influence checking atom-explosion; and therefore that in an aggregation of atoms

* See p. 67.

† The observed effects of particular ether waves in exciting luminosity in matter will presently be cited as giving experimental support to this suggestion.

in which atom-explosion is spreading among similar atoms, in the way just suggested, *there will be a maximum frequency both in time and in distribution in space of the atom explosions.*

Again, the atoms of a mass which are in contact with unimolecular ethers will be most free to explode, for they will be subject to least compression by contiguous expanding atoms; and we therefore conclude that the concerted atom-explosion, whose occurrence we have just argued, will be mostly *confined to atoms at the molecular surfaces which are in contact with unimolecular ethers.*

And finally, since the presence at every free surface, or at any internal molecular surface in contact with unimolecular ethers (p. 40), of a gradation of ether density will tend to make this surface in its wasting by atom explosion follow a surface of equal ether density (p. 51),—the atoms of every projection into a more tenuous layer of ether being more exposed to destruction,—it follows from our argument respecting the form of capillary surfaces (p. 51) that small portions of such a surface will be approximately plane.

Summing up these arguments the important general conclusion is therefore submitted :—

That the explosion of a primary atom at any molecular surface tends to the simultaneous or immediate production of a series of explosions of similar atoms lying at this surface approximately in the same plane, and so placed with regard to the first atom and to each other, that the distances between each exploding atom and the exploding atoms next around it are approximately equal.

The impulses communicated to a mass of unimolecular ether by a series of explosions thus occurring are, it is suggested, the origin of a group of similar ether waves such as propagate light.*

* Irregular atom explosion, producing irregular ether waves, probably occurs to a considerable extent, but it is argued hereafter

Next, as to the nature of these waves :—It is evident that the motion imparted to the ethers by any one of the atoms thus exploding in concert, will be met by similar motions imparted by surrounding atoms ; consequently, the first effect of the concerted explosions will be to produce prism-shaped ether condensations, somewhat resembling in form the walls of a honeycomb, the surface of maximum ether condensation produced by any two contiguous exploding atoms, having all its points equidistant from each of them.

Thus, if, in the accompanying diagram, the points A,A,A, etc., represent the relative positions of a few of the exploding atoms, the hexagonal network of lines about them, drawn to connect the centres of the circumscribing circles of the triangles produced by joining the points, will represent a transverse section of the surfaces of *maximum* ether condensation produced by these exploding atoms.*

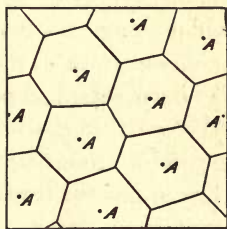


Fig. 11.

Owing to the elasticity of the ethers, their peculiar concentration in this way will be immediately followed by that irregular ether waves can produce neither light, heat, nor chemical action.

An interesting analogy will appear in the sequel between the manner of production of ether waves here suggested, and what will be argued to be the manner of the formation of crystals ; for we shall conclude that the final step in the production of crystals is due to atom expansion, that the expansion of a central atom is followed by the expansion of others around it, and that the greater the space throughout which a similar density of the unimolecular ethers prevails, the greater the size of the crystals.

* The diagram reminds us of the cells of which some kinds of organic tissue are built up. It is suggested in the sequel that one of the producing causes of organic cells is the occurrence of simultaneous expansions at centres suitably distributed throughout the mass.

their expansion, when the ether particles will move towards instead of away from the central axes of the prism-shaped spaces marked out in the way just described ; whereupon, owing to the momentum developed in this new direction, the ethers will be concentrated along these axes.

After this, the ether particles will again radiate much as at first, and then again return to centres, and so on, oscillating to and fro.

The result is seen to be a wave movement, which is partly progressive, in a direction vertically away from the plane of the exploding atoms, partly to and fro, as the particles of ether now pass out from centres to form prism-shaped ether condensations of the kind described, now are centralized again along axes lying between the prism surfaces.

The motions of the ethers which produce the waves are, as above stated, conceived to be merely vibratory,—each ether particle describes some sort of curve, contracting or expanding to accommodate itself to its surroundings as it travels, and returns at last *both to its original position and its original density.*

Since the impulses originate from similar atoms, and these atoms are nearly evenly distributed, *and the concentration at each prism axis which occurs at the close of each complete vibration results from the expansions at six different prism boundaries,* it is evident that the effects of any slight irregularities in the distribution of the originating atoms will, as completed vibrations succeed one another, be so subdivided that they will speedily become inappreciable. For this reason we shall in future depict the transverse section of a few of the prism-shaped surfaces of maximum condensation in a group of ordinary ether waves, *as composed of quite regular hexagons** (see accompanying diagram, fig. 12).

* *Mathematical accuracy* of form would be out of harmony with the variations in detail which are always found in the products of any natural law.

In concluding this sketch of the probable nature of ether waves, it must be observed that, since, as above argued, uniformity of ether conditions is requisite for a number of explosions of atoms of the same kind to accompany or directly follow the explosion of some individual atom in the orderly symmetrical manner supposed, explosions of *other kinds of atoms* are not to be regarded as occurring at the same time and place as these explosions; in other words, the atoms generating each group of ether-waves have their season of explosion *to the exclusion of all other atoms*. Further, the supposed origin of the ether movements in a number of impulses from points approximately in the same plane precludes the supposition that the waves, in any given group, diverge laterally to any appreciable extent.

From the former, it will follow that the *simultaneous emission from the same point* of different kinds of light, or of the same kind of light *in different directions*, must be only apparent, and the seeming continuity of emission should be referred to the inconceivably rapid succession of different series of explosions which start waves in different directions, as the surfaces at which atom explosion is occurring continually change.

The twinkling or flickering effect of distant light, under some conditions, and especially the coloured twinkling of the stars, may perhaps be regarded as favouring these views. And, to prove the possibility of wave production being thus intermittent without appearing to be so, we may cite the fact of the continuance of the effect of light on molecular matter *after the removal of the rays*, shown in *fluorescence*, and also in *the retention of images upon the retina*.

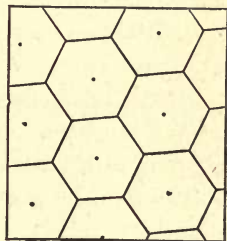


Fig. 12.

The fact of the rectilinear propagation of light supports our conclusion that the waves we have described do not diverge, and also indicates that any vibrations thrown off laterally at the boundaries of a group of such waves are inoperative.*

To show the consistency of the above conclusions with the fact that the intensity of light freely radiating from a luminous centre through a highly transparent medium, varies inversely as the square of the distance from this centre, we remark that, if we conceive an infinite number of small straight rods to radiate from a centre on all sides, and to be uniformly distributed, it is evident the sum of the areas intersected by these rods in any plane of given magnitude and direction, and whose centre always lies in the axis of some particular individual rod, is strictly proportional to the inverse square of the distance of this plane from the centre. And each rod may be taken to represent a group of simultaneously-produced ether waves.†

It should be said that the conclusion just reached—that distinct groups of ether waves emanating from the same point, are always generated in succession and not coinci-

* It will be argued in the sequel that the phenomena of *diffraction*, commonly regarded as cases of light spreading laterally behind an object in the same way that waves in water flow round a rock, are due to *refraction* produced by the gradation of ether density present at the surfaces of bodies which has been already referred to (see p. 50).

The theory of shadows is not considered here because it involves merely the fact, and not the reason, of rectilinear propagation.

† There is an interesting analogy to the combination of strict parallelism of the prism boundaries in the same wave group with a radiation in every direction of succeeding groups, which is here supposed, in the beautiful radiate disposition of prismatic crystals. Thus each individual crystal has its plane faces and rectilinear edges built up in strict relation to the axis of the crystal, while distinct crystals are found inclined to each other at all angles in the most fortuitous manner.

dentally—does not imply that only one group of waves *passes through* the same point at the same time ; it applies to the generation, not to the propagation of ether waves, and while we argue from the above that, to a great extent, ether waves which appear to pass through the same point simultaneously, really do so *in very rapid succession*, we shall conclude that very often, like waves of a more tangible description, ether waves, when crossing one another's path, pass the same point at the same time without being thrown into confusion.*

The reason why permanent displacements of ether, which according to our theories are everywhere taking place, do not ordinarily destroy the continuity or appreciably divert the course † of ether waves we suppose to be that the ether movements of these waves are so rapid that no ordinary motion can displace the ethers to a perceptible extent during their continuance.

The principal evidence in favour of the theory of the production and nature of ether waves offered in this chapter is to be found in the succeeding chapters, in which this theory is used to explain the various phenomena of light, but we may, in closing, mention one or two facts favouring the conclusion that ether waves are due to atom explosion.

Thus the production of light is associated with heat effects, with electrical effects, and with chemical changes.

* The very complicated nature of the conditions prevalent at a point exposed to bright light appears when we remember that it is passed by all the various ether waves emitted in its direction during any instant of time from all points of the luminous surface.

This is shown graphically in the *camera obscura* ; for, while each point of the image receives its light from that portion only of the large luminous surface producing the effect which is intersected by straight lines drawn from this point through the small opening of the camera, *the paths of all the various waves from the entire surface cross one another at this opening.*

† See an exception to this (p. 296).

The generation of electricity has been already traced in some cases to atom explosion, and in the sequel both heat and chemical action are traced to the same source.

Again, light may be produced by breaking lump sugar in the dark, by splitting mica rapidly, or by rupturing ice, and Hawksbee showed in the last century that when common air is passed through mercury in a well-exhausted receiver, the air rushing through the mercury blows it up against the sides of the glass that holds it "appearing all around like a body of fire, consisting of abundance of glowing globules." And that atom explosion should be caused by violence thus done to molecular matter is a natural consequence of the above theory.

CHAPTER XIX.

REFRACTION.

IT is usual in treatises on light to take up the principal phenomena of reflection before dealing with refraction, but here a reverse order is observed, the reason being that, in the light of the conclusions of this treatise, the theory of refraction is not only simpler than the theory of reflection, but is besides required as a stepping stone to that branch of it which relates to reflection at the surfaces of transparent bodies.

Let us then proceed to apply the foregoing results to explain some of the phenomena of *refraction*.

The reason of the different degrees of transparency of different bodies will be considered presently, but, as a basis of the explanation of refraction about to be offered, the following conclusion relating to the relative permeability of different bodies by ether waves is stated here.

Since, as we have already argued, the motions of the unimolecular ethers present among the atoms of a molecular mass are to some extent participated in by the atoms, it is evident that these motions will experience *retardation* in their passage through a molecular mass, *which will be greater or less according to the degree of facility with which the atoms participate in the ether motions*. And if, therefore, the arrangement of the atoms in different substances is such that in some the atoms participate in the movements of the unimolecular ether more readily than in others, or if *in the same substance* the arrangement of the atoms is such

that the atoms participate more readily in the ether movements *occurring in one direction* than they do in those *occurring in another direction*, ether motions which are identical originally will when they encounter these differences come to have different velocities.*

Let us apply this to the case of a group of ether waves passing obliquely from one molecular medium to another. In the accompanying diagram (fig. 13), let AA represent a longitudinal section of one of the prismatic surfaces of maximum ether condensation in a group of ether waves which are passing obliquely from a uniform medium of one

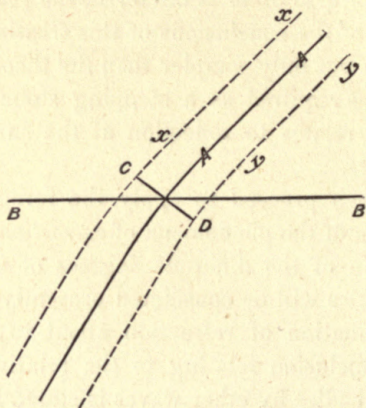


Fig. 13.

kind through a plane boundary BB into a uniform medium of another kind, the molecular *structure* of the media being such that ether motions are more retarded in the lower than in the upper medium. And let xx , yy , be the two prism axes whose opposing radiations form the ether condensation AA .

* The experimental fact that the indices of refraction of different bodies are not regulated by their molecular density may be referred to in connection with this reference of differences of velocity of the ether movements in different substances to molecular *structure*.

If now we draw a perpendicular CD to the line AA at its point of meeting with the line BB , we see that, comparing similar ether motions occurring in the neighbourhood of C and D , those near C will have a greater velocity than those near D .

It follows that the continuation of AA , formed by opposing ether motions radiating from the axes x , y near C and D respectively, *will not be rectilineal*, but will have continual deflection towards D *so long as the opposing ether motions occur wholly or partly in different media.**

All the similarly situated surfaces of maximum condensation in the group of waves will undergo similar bending at the surface BB , and, as the position of the surfaces of maximum condensation determines the position of the subsequent condensations at centres, the united effect upon a group of waves will be to deflect the path of the waves towards the perpendicular drawn to the surface between the two media.

We have thus accounted for the well-known principle in refraction, that when a ray of light enters obliquely a more refracting medium it is bent towards the perpendicular drawn to the surface between the two media.

The following, it is submitted, accounts for the fact of the ratio between the sine of the angle of incidence and the sine of the angle of refraction being constant in the case of any two given media—a property first discovered by experiment by Willebrod Snell, about the year 1621, and known as the “law of sines.”

In the accompanying diagram (fig. 14), let $ABCD$ represent the section of a prism-boundary in its incidence, and in its refraction at a surface MN between two media,

* Some slight deflection will also occur communicated from surfaces of maximum condensation which have come under deflecting influence of this kind to neighbouring surfaces *in the same rank* which have not yet done so.

which are respectively homogeneous, and let $EFGHK$ be the similar section of the next prism boundary.

Through A , a point in the straight portion AB of one section *before* refraction, draw AE parallel to the surface MN and AF perpendicular to AB ; and through D , a point in the straight portion CD of the same section *after* refraction, draw a similar parallel DK , and a similar perpendicular DL .

Then, from the argued nature of ether waves, we conclude—

(1.) That the two sections of the prism boundaries, both

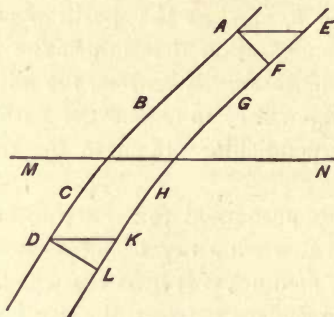


Fig. 14.

in their incidence and in their refraction, have precisely similar loci $ABCD$, $EFGHKL$, similarly situated with respect to the line MN , and therefore that the straight portions AB and EFG and also those CD and HKL are respectively parallel, and that the line $AE =$ line DK .

(2.) That similar ether fluctuations similarly passing out from the same point on a prism axis, one to one prism boundary, the other to the other, considered as to their longitudinal progress, *keep abreast of one another* during refraction,—one traversing the distance from A to D in the same time that the other traverses the distance from F to L .

Now since, from the identical nature of the prism



REFRACTION.

boundaries, an ether fluctuation passes from A to D in the same time that a similar ether fluctuation passes from E to K, it follows from (2) that the same ether fluctuation, or similar ether fluctuations, as the case may be, will occupy the same time in passing from E to F as from K to L.

Consequently the ratio $\frac{EF}{KL}$ is that of the velocities of the same fluctuation in the two different media, and therefore constant.

But $\frac{EF}{AE} = \text{sine of angle } EAF = \text{sine of angle of incidence}$,
and $\frac{KL}{DK} = \text{sine of angle } KDL = \text{sine of angle of refraction}$;
and, therefore, since $AE = DK$, $\frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}} = a$
constant.

This constant, which is the ratio of the two velocities of the ether fluctuations in the two media, is called the *index of refraction*, being different when different media are employed.

If we had supposed the medium *above* BB (fig. 13) to retard ether motions most, we should have had the ether motions near C with a less instead of a greater velocity than those near D, and therefore the refracted beam not drawn towards but driven from the perpendicular to BB. The index of refraction would in this case be less than, instead of greater than unity, but a similar line of argument to that above given would apply.

Simple methods of arriving at some other well known laws are embodied in the following corollaries of the above :—

Corollary 1.—The velocity of light in the refracted ray is to its velocity in the incident ray inversely in the above constant ratio.

For since the frequency of the ether fluctuations must remain precisely the same whatever media the light encounters, the two velocities of a group of waves in the two

B F perpendicular to B C, meeting C D in F. From D draw D G perpendicular to B F produced, and cut off from D F (which must of necessity be greater than the perpendicular D G), a portion D H = D G.

Then the angle B D E is complementary of the angle D B E, and therefore equals the angle of incidence of the ray A B.

And the angle D B F is complementary of the angle C B D₁, and therefore equals the angle of refraction of the same ray.

$\frac{B E}{B D} = \text{sine of the angle B D E, therefore} = \text{sine of the angle of incidence;}$

And $\frac{D H}{B D} = \frac{D G}{B D} = \text{sine of the angle D B F, therefore} = \text{sine of the angle of refraction.}$

Therefore B E : D H :: sine of the angle of incidence : sine of the angle of refraction.

Again, A D, the hypotenuse, is greater than A E, a side of the right-angled triangle A D E.

And similarly C F is greater than C B, and C H is greater than C F.

Much more then is C H greater than C B.

Now, the velocity of light in A B or A D : the velocity in B C or D C :: sine of the angle of incidence : sine of the angle of refraction, which as we have seen above :: B E : D H. Consequently light will travel from E to B in the same time that it will travel from D to H.

But we have shown that A E is less than A D.

Therefore light will travel from A to B in less time than it will travel from A to H through D.

We have further shown that B C is less than H C.

Much more, therefore, will light travel from A to C through B in less time than it will travel from A to C through D.

If D be taken on the other side of B, as at D₁, a perpen-

dicular will have to be drawn to AB at B , and another to BC through D_1 , and a somewhat different arrangement of lines will be presented, but similar reasoning will prove our proposition.

If D be taken somewhere in the surface between the media *out of the plane of incidence*, as at D_2 , and we draw from it a perpendicular to the plane of incidence meeting it in D , it will at once appear that the lines AD_2 , CD_2 , being hypotenuses of right-angled triangles, are respectively greater than AD , CD , which are the sides, and therefore, that this cannot be a course travelled in least time.

Thus, then, we have established that light travelling from A to C , or from C to A , will accomplish the journey in less time if it passes through B , than if it passes through any other point in the plane surface bounding the two media.

The above is an elementary proof of the principle of least time where the surface of the more refracting medium is a plane. If the surface is spherical, the same principle* may be deduced from the following considerations.

If in the above diagram the section of the surface between the media be indicated by a circle touching BD in B , and lines AD_2 , AD_3 be drawn to two points upon it equidistant from, and very near to B , the deduction from, or additions to the time of passage of light travelling from A to C through D_2 and D_3 respectively, which result from the surface on which D_2 and D_3 are taken, being curved instead of plane will approach equality the nearer D_2 and D_3 are taken to B . It follows, therefore, that the increment, or decrement, in the time of passage of light from A to C through points *near* B resulting from the surface being curved instead of plane, may be regarded as similar on both sides of B for very small distances from it;

* Sometimes, however, as we have stated, the course taken by the ray occupies a *maximum* instead of a minimum of time.

or, in other words, that the time of passage from A to C through B will continue a minimum, or will become a maximum.

And since small areas of any surface whatever may, so far as the application of the above arguments is concerned, be regarded as plane or spherical, it follows therefore that the above proposition is true generally.

Corollary 3.—If we take the same media, but reverse the *direction* of the ray of light, so that the incident ray shall be equal but precisely opposite in direction to the former refracted ray, the refracted ray will be equal and precisely opposite in direction to the former incident ray. For if in fig. 14 we suppose the direction of the ether waves reversed, the former direction of refraction being opposite to the present direction of incidence, the velocity of the former refracted ray will be equal to that of the present incident ray, we shall get a precisely converse result to that obtained above, the velocities and other quantities will correspond each to each in the two cases, and the direction of the ether waves after refraction will be opposite to that of the former incident waves.

This is an instance of what is sometimes called the *principle of reversibility*, a principle which is generally found to apply to optical phenomena.

It has been already intimated that the theory of refraction contained in these pages will be made use of to assist in building up a theory of reflection at the surfaces of transparent bodies, and, preparatory to this, before leaving the subject of refraction, let us compare two sections of the prism-shaped surfaces of maximum ether condensation in a group of ether waves taken at right angles to their axes, one made before refraction commences, and the other immediately after it is completed; and we will take the case of a ray of light passing into an isotropic more-refracting medium.

Let fig. 16 represent the section of some of the prism-shaped surfaces of maximum ether condensation and of the prism axes of a group of waves before refraction.

Then, if we suppose that the refraction takes place in a direction horizontal in our diagram (that is to say, if the plane of incidence intersects the plane of our diagram at right angles in a horizontal line), it is evident the relative position of the intersections of the refracted prism axes with a plane at right angles to the course of the waves will be found by projecting the intersections of the incident prism axes (lettered A in fig. 16) by means of perpendiculars to the plane of the diagram drawn

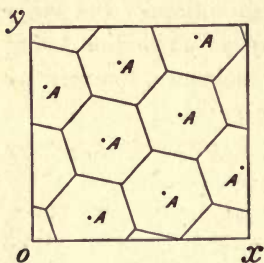


Fig. 16.

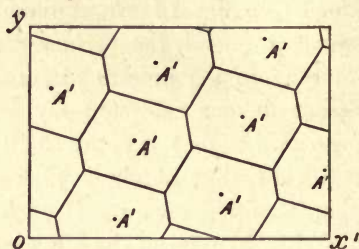


Fig. 17.

through these intersections to meet a plane cutting this plane in a vertical line (as oy), and inclined to it at an angle whose cosine is the ratio of the cosine of the angle of incidence to the cosine of the angle of refraction. And we shall obtain the result of such a projection if taking the vertical line oy and a horizontal line ox , as axes, we set out points corresponding to the points (A) in fig. 16, having the same vertical distances from the axis ox , and distances from the axis oy which are to the horizontal distances of these points from this axis in the ratio of the cosine of the angle of refraction to the cosine of the angle of incidence.

The relative arrangement of points (A') thus derived is shown in fig. 17.

The prism-shaped surfaces of maximum ether condensation will, as before, bisect at right angles lines joining the several intersections of the prism axes, and are depicted in fig. 17.

If a ray passes through a refracting medium whose boundaries are parallel planes, it is evident from the foregoing conclusions not only that, as shown by experience, the ray will have its original direction after it leaves the refracting medium, but that the prism axes of its waves will have the same relative situation, and the prism-shaped surfaces the same form as in the ray before it entered this medium. The waves will, however, we shall argue, have undergone some wasting and other modifying changes, to which reference is made hereafter.

We shall revert again to the subject of refraction presently.

CHAPTER XX.

REFLECTION OF LIGHT AND FURTHER CONSIDERATION
OF REFRACTION.

KEEPING the conclusions just reached in mind, we will now proceed to consider the subject of the *reflection* of light. If a very elastic body is projected against a resisting plane surface, it is driven back from it along a line inclined to a perpendicular upon the surface at an angle approximating to that made by the direction of projection with this perpendicular,* and it is evident that the particles of elastic ether will have this property, and further, that the approximation to equality of the angles will in this case be very close indeed, owing to the freedom of movement which the ether particles possess.

If, therefore, the particles radiating *from* a centre of condensation strike a reflecting plane surface, they will be repelled from it along lines which, if produced, will intersect in a centre situated behind the reflecting surface, whose position relatively to this surface is symmetrical with the position of the radiating centre.

Thus, if in the accompanying diagram (fig. 18), A is a point in a prism axis from which particles are being radiated upon the surface BC, the point D lying in the

* We have a familiar instance of this in the reflection of billiard balls from the cushions of a billiard table, the motions being so perfectly reliable, that experience enables a skilful player to accomplish marvellous feats of dexterity.

normal drawn through A, and equidistant from the surface BC, will be the point in which the paths of the reflected particles, produced through the surface, intersect each other, and these reflected particles will act precisely as though they proceeded from a centre at D, similar to the actual centre at A.

It follows that the moving particles of a group of ether waves reflected from a plane surface, and the prism-shaped surfaces they produce, have the same courses and situations relatively to the plane of the surface *on one side of it*, as the same particles and the prism-shaped surfaces produced would have had to this plane *on the other side of it*, if the waves *had not been intercepted, but had continued in the path of their incidence*. And this involves the well-known law of reflection, that the angle of incidence equals the angle of reflection.

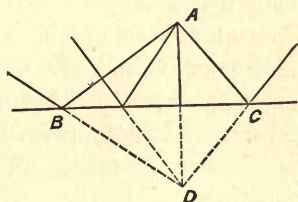


Fig. 18.

As to the form and qualities requisite in a surface that reflection of light may occur, we observe—

That, since our arguments go to show that for ether waves to produce the sensation of light they must have the regularity of structure we have endeavoured to describe, it would seem that, for a surface to reflect light, it must consist of a number of true planes each of sufficient magnitude to reflect without distortion a considerable number of the synchronous vibrations associated in a single group of waves; for the prism-shaped surfaces in a group of waves will not have the same form after reflection as before unless the reflecting surface is plane.

This, however, appears at first to involve a contradiction, for if the surfaces of all masses of molecules are being continually eaten away through the successive explosion

and return to the state of unimolecular ethers of the atoms composing them, all such surfaces will necessarily be *rough* when very small portions are considered, and not smooth as just supposed, and besides, as a matter of experience, all or nearly all surfaces however rough do reflect light.

The reconciliation of this apparent contradiction is found in the conclusion already reached that at all free molecular surfaces layers of highly-condensed unimolecular ethers are present (see p. 50), for we see at once that this involves the filling up of hollows in the surface of the molecular mass with highly-condensed unimolecular ethers, and, if we suppose that reflection takes place from the stratum of ethers of high density, and not from the actual molecular boundary, we have a dense surface provided entirely free from abrupt irregularities when regarded with sufficient minuteness, and which may therefore be considered as made up of true planes more or less minute.

According to this view the difference between reflection from a surface which we account rough, and that from a surface which we perceive to be smooth, is, that in the case of the rough surface, the planes composing it are very minute and inclined at all conceivable angles, so that the various groups of reflected waves pass in every conceivable direction, while in the case of the smooth surface these planes are nearly coincident in direction over comparatively large areas, so that groups of waves having the same direction before reflection, if they strike the surface nearly at the same point, have nearly the same direction after reflection.

In the case of *diffused light*—i.e., light reflected from a rough surface and which passes indifferently in all directions—the planes from which the reflections occur are commonly so minute as to make it impossible to trace

them, but in some cases, as in that of powdered glass or snow, the origin of the surface assures us that it consists of innumerable small planes inclined at various angles.

It is a familiar fact that for a solid surface to possess high reflecting power it must either naturally, as in the case of crystals, or through artificial treatment be smooth or polished ; the surfaces of liquids, through the operation of the laws of gravitation and capillary action, always tend to assume the molecularly even condition necessary for considerable reflection.

Although slight disturbing forces produce broken reflection at the surfaces of liquids, we notice that neither in solids nor liquids do the minute tremors and fluctuations, which we have concluded are continually passing through all masses of molecules, interfere with their reflection. Thus, although, as we have concluded (p. 70), the atoms at the reflecting surface of a sheet of glass, as well as all the other atoms composing the glass, are in a continual state of movement, it is a movement which is quite unbetrayed by the reflection.

The explanation which naturally suggests itself is that the adherent unimolecular ethers have such freedom of movement that the actual molecular surface can undergo *minute* fluctuation without perceptibly impairing the truth of the reflecting surface of unimolecular ethers lying above it ; and such a facility of ether movement as this supposes has already been pictured in connection with our theory of electrical conduction.

Another condition requisite in a surface that it may have good reflecting power is *comparative rigidity*, for, if the particles of ether which compose it readily take up the motions of the ether waves impinging upon them, it is manifest that, to the extent they do so, transmission and not reflection of these motions will be the result ; we want for good reflection a surface which presents an impenetrable

wall to ether motions, turning them back as a breakwater turns back waves of water.

This harmonizes with the fact that the metals, especially in a solid condition, are the best reflectors, their density indicating a closeness of texture which prevents their ether particles from at all readily taking up the wave vibrations of the unmoolecular ethers.

The reason why many substances of a crystalline texture, whose hardness we suppose indicates that some of their atoms are even more condensed than those of the hardest metals, have but indifferent reflecting power as compared with metals, would appear to be that, as already argued, their structure is cellular ; so that ether motions are readily transmitted from the partly expanded ether of one cell-interior to the partly expanded ether of another cell-interior through the flexible cell walls. *

It is a familiar fact that reflection is greater when light falls very obliquely, so that, although when we look into the waters of a still pond at our feet we may be able to see the swift motions of the fish, and even count the pebbles at the bottom, if we raise our eyes the trees and sky and grasses on the further bank are faithfully mirrored as in a sheet of silver.

The explanation in this and kindred instances appears to lie chiefly in the well-known fact, that elastic surfaces, in all cases, have more power to repel a body when it falls obliquely than when it falls perpendicularly upon them, instances indeed being known where a moving body falling very obliquely is reflected, and retains considerable velocity, when, if it had fallen more directly, it would have penetrated the opposing substance.†

* We shall find this an important conclusion in explaining the transparency of crystalline bodies.

† For example, persons have been injured by bullets discharged at waterfowl, which have struck the water very obliquely and been reflected from its surface.

Such an explanation does not however cover all the ground, indeed it is evidently inapplicable to the case of increased reflection produced as light falls more and more obliquely on the surface of a *less-refracting* medium ; the line of argument which follows will, it is believed, adequately deal with all cases for which the above explanation is inadequate.

We will now, with the aid of the conclusions already reached as to the causes of refraction, proceed to investigate cases in which reflection is associated with considerable transmission.

There is, perhaps, little difficulty in conceiving that molecules may be so condensed and closely aggregated as to oppose an effectual barrier to the transmission of the vibrations of the ether waves—that they may be rigid enough to produce that elastic repulsion of the ether particles which constitutes reflection—and the existence of the metals with their brilliant powers of reflecting seems to justify this view ; but what are we to say when we find a molecular substance so constituted as to afford great facility for the transmission of light, and at the same time evincing considerable reflecting power ; and that, not only with regard to rays which strike its surface *externally* as they come to it from a less-refracting medium, but also with regard to the same, or other rays when they strike the surface *internally* as they pass *into* a less-refracting medium from within the substance ; reflection being indeed in this case often more considerable ? Are we to suppose that some kinds of the atoms which compose the reflecting substance are pervious, while the rest are impervious to the ether motions of the incident waves ; and, if so, how are we to account for the preservation of symmetry of both reflected and transmitted vibrations, evidenced by their light-producing power ? And, further, how will such a supposition at all account for internal

reflection at the surface of a refracting medium when the ray in its incidence is passing *towards* the less-refracting substance? Evidently some other explanation must be sought.

Let us consider first the case of reflection occurring when light passes into a *transparent more-refracting medium*.

We have concluded that refraction is due to the ether motions having a less velocity in a more-refracting medium than in a less-refracting medium, and it follows that when the particles of ether radiating from any centre of condensation in an ether wave pass a molecular boundary into a more-refracting medium they will experience a sudden check and some only of them will pursue their course.*

Further the ether particles thus checked will accumulate, or be condensed, at the surface of the more-refracting medium, and in this way produce, for the moment, a layer of highly condensed unimolecular ether, and if this layer, like the layers of condensed unimolecular ether which we have concluded are attached to molecular surfaces, is capable of reflecting ether particles, each fluctuation as it strikes the more-refracting medium will thus furnish its own reflecting surface from which some of its particles will be reflected.

And, finally, the same proportion of particles being reflected in the same manner in each similar fluctuation, both the portion of the waves transmitted and the portion reflected will have the unbroken symmetry which we have argued is a necessary characteristic of ether waves if they are to produce light.

We have therefore a feasible explanation of this case.

* To use a rough illustration it will be as when a stream of water, is partially dammed back by some obstacle, so that while it arrives at the obstacle at the rate of so many gallons per second, it passes off by the proper channel at some less rate.

If we wish to ascertain in what way, if any, the reflected and the transmitted waves will differ from ordinary waves we must carry our investigation further :—

In cases where the light strikes vertically, so that the prism-axes have the same relative situations *after* the refracting surface is passed as *before*, the proportion of each fluctuation turned back will be determined solely by the ratio of the respective velocities in the two media, and both the reflected and transmitted waves may be expected to be of the ordinary kind.

But, when the light strikes the more-refracting medium obliquely, so that the prism-axes in the transmitted waves are found further apart (p. 218), the proportion reflected and the proportion transmitted of each fluctuation in a group of waves will be determined, not only by the ratio of the velocities, but also by the increase of the distances between the prism-axes—the latter, by giving more time to each fluctuation entering the second medium before it encounters an adjoining fluctuation, producing increased capacity of transmission at the boundary between the media.

And further, since in the latter case the distances between the prism-axes suffer the greatest increase in the direction of the plane of incidence, and no increase in a direction at right angles to this (p. 218), the portions of each fluctuation whose direction is nearest to that of the plane of incidence will experience most of the increased capacity of transmission ; indeed generally *the proportions of any given fluctuation transmitted and reflected will not be the same in all parts of it but will vary according to the direction of radiation of the ether particles observed.*

Next, as to the case of *internal* reflection, *i.e.*, of reflection as light passes into a *transparent less-refracting* medium.

We see that in this case there is no diminution of velocity when the fresh medium is entered, as there was in

the former case, but that *when the light strikes obliquely* there is a change which produces somewhat similar effects—a diminution of the distances between the prism-axes which gives *less time* to each fluctuation before it encounters an adjoining fluctuation, and thus diminishes the capacity of transmission at the boundary between the media. And it is evident that, when this effect is greater than can be neutralized by the increased velocity, the particles of ether will experience a check, and each fluctuation as it seeks to pass out into the less-refracting medium will momentarily produce an aggregation of highly condensed unimolecular ether which, like that produced in the former case, will, we may conclude, form a reflecting surface; and such surfaces collectively will be more or less continuous according to the degree of contraction of the space for radiation allotted to each fluctuation which is thus produced.

This, it is suggested, explains the increased reflection observed as light falls more and more obliquely on the surface of a less-refracting medium; *total reflection*, to which reference will be made presently, occurring when the surfaces of condensed ether, produced as just explained, are sufficiently continuous.

A similar argument to that on p. 227 may be used to show that the proportions of any given fluctuation transmitted and reflected in the case just considered will not be the same in all parts of it, but will vary somewhat according to the direction of radiation of the ether particles observed; this conclusion, with the kindred conclusion previously reached in the case of refraction by a more-refracting medium, will presently be found important in explaining the phenomenon of polarization by reflection.

Perhaps one of the best, as well as one of the most familiar instances of internal reflection presents itself when we approach a plate-glass window at night with a

REFLECTION OF LIGHT.

lighted candle. On looking obliquely at the reflection of the candle in the glass we see several images one behind another, the greatest number being observed when the reflection is most oblique. The first and second of the series are the brightest, and of nearly equal intensity, and the rest have a regular gradation of diminishing intensity. This effect is analyzed in the accompanying diagram, in which *A* is supposed to be the position of the candle, *E* that of the observer.

The portion of the direct rays from the candle (*A*) which

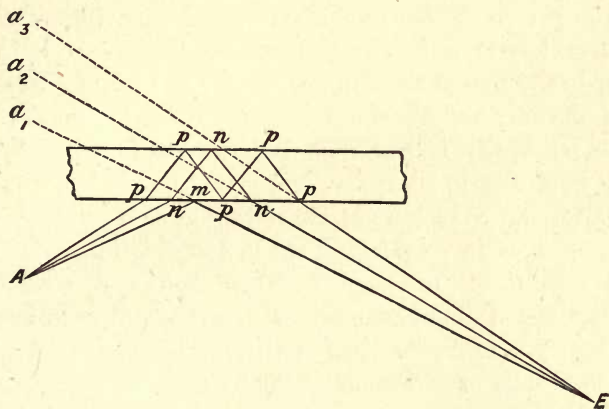


Fig. 19.

enters the glass experiences, when it reaches the further surface, partial internal reflection such as above described; and in like manner the part thus reflected is in its turn partially reflected at the front surface of the glass, and so on; the successive internal reflections forming zigzags between the two surfaces of the glass, along which rays of light pass whose intensity is less and less as portion after portion of them escapes.

In the diagram the courses of the central rays concerned in producing three of the images are depicted.

These courses are marked $A m E$, $A n n n E$, and $A p p p p p E$ respectively. The first image is the result of one external reflection, and its apparent position is a_1 ; the second is the result of one internal reflection and the accompanying refractions, and its apparent position is a_2 ; the third is the result of three internal reflections and the accompanying refractions, and its apparent position is a_3 .

The fact that the first and second images are about equal in intensity shows that the portion of the undiminished rays reflected from the external surface is only equal to the portion of *the remainder* reflected from the internal surface less that part of this portion withdrawn by internal reflection at the anterior surface as the rays re-issue into the air, and therefore that the reflecting power of glass externally is less than it is internally when light falls at a certain obliquity.

If, instead of looking at the reflection of a candle from a window, as just explained, we look through the window obliquely at the candle, we see, as before, a series of images one behind another; but the first will in this case be simply a refracted image; the remaining images will be the results of reflection internally from the surfaces, as in the former case.

When, instead of using a clear plate of glass as a reflector, we employ a mirror, we have a greater number of images because the mercury has immensely greater reflecting power; and the second image which is produced by the metallic surface is far the brightest, unless indeed the angle at which we look is so oblique as to very greatly reduce the transmitted rays by reflection at the outer surface. When we use a mirror all the reflections at the posterior surface are, according to the previous arguments, instances of reflection from the layer of highly condensed ether adherent to a molecular surface, not

instances of reflection due to restrained transmission as in the former case.*

Before leaving the subject of internal reflection, just a few words must be said as to what is known as *total reflection*. In the accompanying diagram (fig. 20), let AB represent the section of a plane surface between two different uniform media, the lower one being the more refracting medium, and let mnp represent the section before and after refraction of the space between two adjacent prism-shaped surfaces of maximum condensation in a group of waves which are passing from the more-refracting to the less-refracting medium.

Then it is evident that the more obliquely the waves meet the surface AB , the more narrowed or flattened will

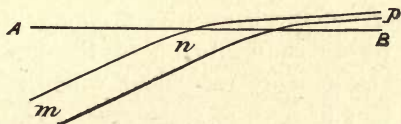


Fig. 20

this space become after refraction, and, as already stated, the less will be the portion of each fluctuation transmitted, the greater the portion reflected; and that if the waves fall very obliquely the space available for radiation from

* From a consideration of the diagram (fig. 19), we see that no two images, seen as proposed, present the *same view* of the candle; for, what we see is precisely equivalent to a row of precisely similar candles, that is, differing only in their diminished order of intensity, similarly placed one behind another; and it is manifest that, in such a row, the further back a candle stands, the less of a side view and the more of a front view we obtain of it; and it is evident that the further removed the candle is from the reflecting surface the more closely the different views of it presented by the multiple images will resemble each other, the smaller will be their angles of separation at the eye of the observer, and the more they will overlap.

From this we see that if, instead of a candle, we look at the reflection of a luminous body whose distance is very great, *e.g.*, the

each centre will become so contracted that the waves transmitted will be unable to preserve their individuality, and therefore unable to produce light, and thus that total reflection will ensue. This conclusion is justified by experience.

Instances of total reflection are enumerated in all the text books. One such, a favourite and most beautiful instance, is furnished by a jet of water projected horizontally, illuminated by a ray of light travelling in the same direction as and within the jet. In this case the light is, through repeated internal reflections, carried down with the water from its horizontal path, and the water kindles and sparkles like liquid fire.*

The *critical*, or *limiting angle*, so called as being the angle at which total reflection commences, is usually stated to be that angle of incidence which, on applying the law of refraction before enunciated, gives the direction of the refracted ray as actually coincident with the surface between the media; in experience, however, as just intimated, no light is transmitted when the direction after refraction would very nearly coincide with the direction of the surface between the media.

From the arguments which have been presented, as to

moon, or a star, all the multiple images should practically coincide and appear as one image only.

When, as sometimes happens, we see multiple images of the moon on looking through a plate-glass window, the effect arises from the glass not being perfectly homogeneous; and, in accordance with this, it is found that the multiple images, when they occur, have various distances apart in different instances, and various positions with respect to the observer quite irrespective of the plane of reflection.

* It may be noticed that if it were not for the broken nature of the surface of the jet, due to the continual rearrangement of its particles (p. 52) and the presence of foreign particles within it, the rays of light would always strike the surface of the jet so as to be *entirely* subject to total reflection, and would therefore be invisible.

the cause of internal reflection, we arrive at the important conclusion that it is not necessary to have a *sharply defined surface* between two media for total reflection to occur—in other words, that the increase of refracting power necessary to produce this phenomenon may be gradually and not suddenly reached; the effect in this case partaking partly of the nature of refraction and partly of the nature of reflection.

For, suppose rays to strike obliquely to the *stratification* of a medium made up of an indefinite number of thin layers of successively less refractive power, so that the rays are gradually bent round as they pass through the successive strata, and each refracted prism becomes more and more flattened. Evidently, in such a case, we should as before, at last reach a stratum at which the space available for radiation from each prism-axis becomes so contracted that no waves capable of producing light are transmitted, and thus, practically, the whole of the rays are reflected.

The amount of refraction experienced by the incident rays in passing through a medium of increasing refractive power before reaching this totally-reflecting stratum will evidently be exactly counterbalanced by the reverse refraction similarly encountered by the reflected rays, so that here, as in ordinary total reflection, the law will hold that the angle of incidence equals the angle of reflection.

To make the above clearer, see the accompanying diagram (fig. 21), in which a medium is supposed to have uniform refracting power from A to B, and then to decrease gradually in refracting power from B to C. A group of prisms, D, are represented as passing obliquely into this medium of graduated density, and as being, in consequence, when they pass below BB, gradually bent round towards the direction of stratification of the medium, so that they strike a stratum EE with sufficient obliquity for total re-

flection to occur. The courses of the reflected prisms are shown as symmetrical to those of the incident prisms.

An instance of total, or nearly total reflection occurring where there is no sharply defined boundary between media of differing refractive power appears to be found in *the mirage*, that strange often-described phenomenon in which parched and tenuous air closely mimics the appearance of extensive tracts of water, giving the most perfect reflection of sky, trees, and other objects.*

The simplest form of mirage appears to be due to a level surface of greatly heated sand so heating the air next to it, that, although this heated air is continually rising and mixing with the cooler air above it, there is a steep gra-

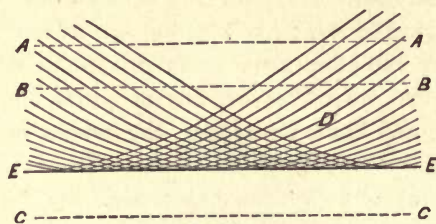


Fig. 21.

dation of increasing density upwards, which furnishes a medium that is more and more refracting in an upward direction.

The fact that the trees and other objects seen in a mirage are frequently found to be hidden from view when the

* Dr. Thomson, in his "Land and the Book," remarks that the name for mirage in Sanscrit means "the thirst of the antelope," and gives us his experience as follows:—"I once gave chase to a flock of gazelles on the plain of Tireh, south-east of Aleppo. The day was intensely hot, and the antelopes made direct towards a vast mirage, which covered the whole eastern horizon. To me they seemed to be literally leaping through the water, and I could see their figures *below* the surface, and *reversed*, with the utmost distinctness. No wonder they were deceived, for we, their pursuers, were utterly confounded."

phenomenon has passed, appears to be accounted for by refraction accompanying the reflection—Under ordinary atmospheric conditions the objects are hidden from view by the nature of the ground, but the gradation of density in the air which produces reflection, and thus gives the appearance of water, produces also refraction, which bends the rays from objects situated below the line of sight, round the intervening rising ground, and thus apparently lifts the objects into view during the continuance of the mirage.

The effect called *looming*, which is experienced in calms at sea, and by which shadowy inverted images of objects are seen immediately over the objects themselves, is explained in a similar manner, except that in this case the heated, and therefore less refracting air is *above* instead of below.

We have not, in our consideration either of reflection or of refraction, treated of the phenomena produced by curved surfaces, and it does not come within the scope of this treatise to do so, because the various effects produced when reflecting or refracting surfaces are curved are all mathematically deducible from the plane effects, and do not throw any light upon the theories here put forward. We need only call the reader's attention, in passing, to the facts that all curved surfaces may be treated as made up of an indefinite number of very small plane surfaces placed at right-angles to the normals of the curved surfaces ; and that, in harmony with our conclusions as to the constancy of the shape of the prism-shaped surfaces of maximum condensation in the ether waves as long as their course is through the same medium, lenses or curved mirrors need not be supposed able to cause either convergence or divergence of these surfaces or of the prism-axes in any given group of ether waves, but merely to cause a larger or smaller number of groups to pass in particular directions.

Thus, bringing rays to a focus is not to be regarded as a squeezing together into a small space of a number of ether waves, but as an increase of their number and frequency at some particular point.

A few remarks as to how the structure of bodies regulates their relative transparency will be made when the suppression of rays of light in the course of their passage through bodies has been treated of.

Our subsequent consideration of the subject of heat will throw light on the fact that refraction uniformly diminishes as temperature increases.

We may remark, in closing this chapter, that where the colour of reflected rays differs from that of the incident rays which produce them, as in cases of diffused light coming from coloured substances, it has been shown that the cause is not any peculiarity of reflection, but lies in the suppression of some of the incident rays; the cause of this suppression we shall endeavour to explain hereafter.

CHAPTER XXI.

DISPERSION.

THE origin of ether waves suggested in this treatise (p. 202) implies difference of scale in the vibrations of different series of waves, according to the kind of atoms setting up the waves by their explosion, and the nature of the ether conditions prevailing about these atoms when they explode ; * each group of waves, as we have argued, preserving its individual kind of vibration throughout, but succeeding groups generally presenting different kinds, except only when the light is monochromatic. We have hitherto considered ether waves without reference to their magnitude ; in the present chapter it is proposed to deal with phenomena which reveal a difference in scale, or magnitude of different waves.

At the first glance, the glorious softly graduated succession of the seven rainbow colours known as the spectrum, resulting from the fan-like expansion of a ray of white light by a prism, naturally suggests the discrimination of light into seven kinds having the seven different colours, or into some less number of kinds whose superposition, or combination in the spectrum, produces these seven colours ; but upon examination it is found that colour is a subordinate feature,† that the

* See further as to this, p. 242.

† As to colour, see p. 257.

analysis made by a prism is not a matter of colour—this depending merely on the effect on our senses*—but *a matter of degree of refrangibility.*

For, since the constancy of the effect produced shows that each separate kind of light is uniformly refracted, we see that *light of any one kind only* is not “dispersed,”—*i.e.*, rendered more divergent—by passage through the prism; indeed this receives direct proof if a ray of monochromatic light issuing from a narrow slit is passed through a prism, the size of its image on a screen not being thereby appreciably increased. And the wide continuous band of illumination of the spectrum must therefore be regarded as made up of a large number of lines of light of the same magnitude as the narrow line of white light seen when the prism is withdrawn; † each of these lines, whose combined effect gives continuous illumination from end to end of the visible spectrum, consisting of light of a

* In connection with this wonderfully beautiful phenomenon, the spectrum, we cannot refrain from reminding the reader that mere mathematical or mechanical conditions can in no case suffice to *produce a sensation*, but merely constitute the machinery which transmits or concentrates effects. Look at that band of gorgeous colours! Theoretically, it is just a collection of ether waves similarly organized, but having some difference of scale. Actually, to the soul of man it is a ravishing harmony in his inner nature awakened by the touch of Nature’s fingers. The pleasure, and the sense of beauty and fitness which we feel in beholding this or any other beautiful natural phenomenon are in no way accounted for by its mere mechanism; they are a *separate* creation foreseen and sympathized with by the great Creator, who must have experienced the pleasure before He endued His creatures with power to participate in it:—“God saw that it was good.”

† A continuous spectrum, in which a thin line only of each kind of light is found, and overlapping of the different kinds avoided, is called a *pure spectrum*; it can be obtained in several ways, but perhaps the simplest method is to use light passed through a fine slit.

particular kind having its own characteristic degree of refrangibility by the prism.*

As to the source of the difference in refrangibility of different kinds of light, it is suggested that the retarding effect, already explained, exercised by the atoms composing a refracting body on the ether motions of the waves which traverse it, is more considerable the more rapid these motions are; because the slower and less frequently repeated the ether motions, the more the atoms can participate in them; consequently that difference of refrangibility depends on difference in the time of pulsation of the waves refracted—waves whose pulsations are more rapid being more refracted, those whose pulsations are less rapid being less so.†

The fact that the amount of dispersion a refracting body produces becomes less as its temperature increases, appears to be in harmony with this suggestion, for we shall argue hereafter that rise of temperature indicates an increase in the quantity of unimolecular ethers present, and this would be likely to cause increased participation by the molecules in the more rapid

* We may here refer to the important fact that a dark continuation of the spectrum is present in both directions beyond the visible bands of colour. In other words, there are ether waves to which the foregoing argument applies, having, some a greater, some a less refrangibility than the waves of light. The presence of those beyond the red end is manifested by their heat (see p. 309), that of those beyond the violet end by their production of fluorescence in certain bodies. These dark waves obey similar laws of refraction and reflection to those which rule the waves of light, and must therefore be regarded as of a precisely similar nature to the light waves; a proof not only that the primary distinction between the waves has nothing to do with colour, but more than this, that it has nothing to do with light-producing power.

† This is in harmony with the conclusion otherwise reached, that the shorter waves are found at the blue end of the spectrum, the longer at the red end.

ether movements, involving lessened retardation of the shorter waves.

Prisms formed of certain substances give spectra of *abnormal dispersion*, the colours being arranged so that, as to their order of succession, it appears as though opposite portions of two normal spectra were lying partly one over another.

A curious experiment made by De Klerker in 1879 with one of these substances* is suggestive of the cause of the phenomenon. He employed two hollow prisms of equal angle, turned opposite ways, and filled with alcohol. Through such a combination light passes, as we know, without refraction or dispersion. When a few drops of a fuchsine solution were added to the contents of one of the prisms, the yellow, orange, and red rays (in the order named) began to separate themselves from the others. This process could be carried on until the solution was so strong that it transmitted no visible light. All this time the blue and violet rays remained apparently unrefracted—the yellow, orange, and red showing continually increasing refraction. The following, based on our hypothesis that the ether is of two kinds, seems a probable explanation.

Since the fuchsine is added to the contents of one only of the prisms, and its addition produces refraction of the rays towards the red end of the spectrum only, it is evident that so far as the remaining rays are concerned, the presence of the fuchsine makes no alteration in refracting power; and it would seem, therefore, that in the mixture we have a dual medium, one part of which, the fuchsine solution, transmits the rays towards the red end of the spectrum more readily than the rays towards the violet end while the remaining constituent, the alcohol, transmits all the rays with equal facility.

* Taken from "Enc. Brit.," Art. "Light," p. 602.

In iodine vapour, which is one of the substances giving abnormal dispersion, it is noticeable that the dispersion is less as the temperature is higher.

The phenomena of dispersion supply important evidence in support of our theory of the origin of ether waves, for, as we should expect from the foregoing arguments, *the nature of the spectrum produced by a given prism is found to depend on the nature of the light source*—dispersion proves a revealer of secrets, and in telling us what particular waves produce a given ray, informs us of the nature of the molecules whose incandescence originates the waves.

The disentangling, by the use of a prism, of the various combinations of waves which are concerned in producing the characteristic light of different incandescent bodies has become an important science, the science of *Spectrum Analysis*, and a separate chapter will be devoted to this subject after we have considered the subjects of Heat and Chemistry ; we may, however, mention here one or two conspicuous facts.

Perhaps the most significant is the fact that the spectrum of any one of the elements in a gaseous state, when incandescence has been produced in a certain way, consists of but a few narrow lines,* whose position is strictly characteristic of the element made use of, nearly all the terms of the continuous series composing a complete spectrum being entirely absent.

The natural explanation evidently is, that, when the conditions obtaining are sufficiently simple, the explosions produced by each particular kind of primary atom in a given element are of precisely uniform violence, and have uniform frequency in time and space, and so produce waves of one uniform *time of pulsation* characteristic of this particular kind of primary atom ; each kind of waves, having its own constant place in the spectrum.

* In some few cases a thin bright line stands alone.

The complementary fact that greater condensation in the incandescent body gives a great variety of variously refrangible kinds of light covering large continuous tracts of the spectrum, or extending throughout it, also receives a natural explanation. For we see that when we have not the freeness and uniformity which, according to our arguments, prevail in the tenuous gaseous state, particular primary atoms, instead of producing waves of uniform time of pulsation, may be expected to produce a variety of waves whose times of pulsation somewhat differ in different groups of waves, the result being that, instead of ether waves of a particular wave-length, we have waves presenting a continuous series of wave-lengths whose mean is some particular wave-length, covering continuous tracts of the spectrum of greater or less extent.

Another important fact is that increased incandescence of a solid, or liquid body extends the tract it occupies in the spectrum *in the direction of the violet end*, the light emitted containing more and more refrangible rays as the incandescence increases.

This was shown by Dr. Draper many years ago. He employed a voltaic current to heat a platinum wire, and studied by means of a prism the successive introduction of the colours of the spectrum. A familiar example of the fact, scarcely requiring the aid of a prism to prove it, is seen when we heat a poker; for it rises from a black heat to a red heat, and from a red heat to a white heat.

The explanation of this would appear to be that increased incandescence is simply increased frequency in time and space of atom explosions, so that its occurrence not only makes the number of the groups of waves which are successively produced greater, but also makes the distances between the centres of explosion in some of them less, giving waves with shorter time of pulsation, *i.e.*, more refrangible waves.

Finally, there is one other fact we will allude to here, which, besides confirming our conclusions from the other facts that have been mentioned, forms our first introduction to a very important effect of ether waves on one another, which will again and again, in various shapes, invite our attention in dealing further with the phenomena of light :—

In a pure spectrum of an incandescent body the otherwise continuous tract of various kinds of light presented is found, in cases where the incandescence is violent, to be intersected by dark lines more or less numerous, the well-known Fraunhofer's lines, first discovered in the spectrum of the sun by the observer of that name.* The position of these dark lines in the spectrum is precisely that of the bright lines which form the fragmentary spectrum of the incandescent body *when in the state of vapour*, and experiment has shown that the effect is due to a power possessed by the vapour of a substance of blotting out light of the particular kind this vapour would itself emit if incandescent.

We see at once that the existence of Fraunhofer's lines in pure spectra confirms our previous conclusion, that the complete spectrum is made up of successive distinct terms, of which each is produced by groups of waves of one definite wave-length only, so that finely graduated as the series is, we should find, if our sensibility were delicate enough, that it consists of terms distinctly various in place and intermittent in production.†

* As we shall notice hereafter, Fraunhofer's lines in the solar spectrum are considered to result from the blotting out, or, rather, weakening of certain rays through the intervention of a flaming atmosphere supposed to be present around the nucleus of the sun.

† As already remarked, flashes of colour to be seen in the twinkling of some stars seem to illustrate our conception of distinct groups of ether waves of different kinds following one another in rapid succession.

As to the way in which the lines are produced:—If of the various kinds of waves passing through any given mass of vapour some have the wave-length of waves which would be produced by explosion of the atoms composing the vapour, it is evident that wherever these particular waves produce concerted atom explosion in the vapour, and thus set up ether pulsation synchronous with their own, an amalgamation of the ether pulsations of different origin thus coming together must be looked for; and, except in cases where the one set of pulsations are so timed in relation to the other set as to produce merely an intensification of the vibration,* this will result in the production of modified waves having different refrangibility from their components, and, indeed, probably incapable of producing light.† And thus, in cases where the atom explosion produced in a vapour is considerable enough, a weakening or blotting out of particular wave-lengths will be manifest in the spectrum of light passed through this vapour.

In harmony with this explanation, we suppose that it is *not extinction but modification* of certain waves which causes the dark breaks in the spectrum known as Fraunhofer's lines.

The occurrence in the path of ether waves of a comparatively small amount of atom explosion productive of similar waves is adequate, it would appear, to modify the waves sufficiently to destroy their light, even in cases where the brilliancy of the incident light would indicate that groups of powerful waves are following one another with great rapidity.

* See p. 248.

† The sensation of light is hereafter argued to be due to atom explosion at the retina, and it is supposed that atoms liable to be exploded by the uncombined waves would not be similarly affected by the waves of shorter pulsation resulting from the amalgamation.

The fact that a medium of incandescent vapour blots out from a continuous spectrum only the narrow lines of colour which belong to the spectrum of the light it emits, must be taken to indicate a necessity for complete identity of the rates of pulsation of two superimposed groups of waves, that they may amalgamate and form one modified group.

The reason why the similar ether waves from two different sources of light, or from different points at the same source, when they happen to travel together, are not in the ordinary way mutually destructive of the power of producing light, appears to be that the travelling together of similar light from two different sources merely means an increase of the number of the groups of waves of a certain kind travelling in the given direction, and does not generally involve the amalgamation of one group with another.

In closing these few remarks on dispersion, we observe that the explanation of the phenomenon which has been offered affords striking corroboration of the theory that each of the so-called elementary substances is an aggregation of particular kinds of primary atoms.*

* See p. 19.

CHAPTER XXII.

PRODUCTION OF IRIDESCENCE BY INTERFERENCE—DIFFRACTION—COLOUR PRODUCED BY THE PRESENCE OF DUST OR SMALL PARTICLES.

THE theory offered in the last chapter of the amalgamation of two groups of the same kind of ether waves when they travel in the same direction and are superimposed applies to what is known as *interference*, and some details of the theory come out with great clearness in connection with the phenomenon of iridescence attributed to this cause.

If a drop of paraffin is placed upon the surface of water, the laws of attraction cause it to spread out into a very thin film (p. 53), and as the film diminishes in thickness gorgeous colours of different hues are successively displayed.

That these colours are not in any way peculiar to the materials employed, but are simply functions of the varying thickness of the thin film, is proved by an experiment made by Newton, which furnishes an admirable analysis of the nature of the phenomenon.

To get a film of variable, and, at the same time, calculable thickness he took a plano-convex glass lens of very feeble curvature, and laid upon it a plate of glass with a plane surface. He then found that the film of air between the lens and the glass plate furnished a characteristic system of colour arranged in concentric rings about the central point

of contact.* When he used monochromatic light a series of bright rings, separated by dark ones, was produced ; and he found that the thickness of the glass, measured successively at each bright band of this series, gave a series of values in arithmetical progression, and that, taking successive series, the differences between succeeding terms, were less and less in passing along the spectrum from the red towards the violet—in other words, that the rings and the dark spaces between them were narrower and yet narrower in the different series as the light selected had its place nearer the violet.

Finally, add to these observations the fact that, travelling out from the centre, the film presently becomes too thick to produce any colour effect.

The received theory of the colours of thin films is, that ether waves reflected from the upper surface of a film being followed by precisely similar waves reflected from its under-surface, the two sets of similar waves passing in the same direction, one upon the heels of the other, produce interference and mutual extinction, *in cases where the thickness of the film has approximately a certain proportion, or a proportion which is some multiple of this, to the wavelength* ; so that, when white light is employed, each particular thickness extinguishes certain colours, and consequently shines with the colours complementary to these.

This is evidently very much in harmony with the theory of the amalgamation of two groups of similar ether waves

* The experiment throws some light on the molecular structure of glass, for it is found that considerable pressure has to be exerted in bringing together the two pieces of glass to show a black spot in the centre of the rings, and this would seem to indicate that the surfaces are in such a molecularly vibratory condition, and, moreover, that the vibrations are so vigorous, that the two surfaces do not have continuous contact until a considerable force has overcome the oscillations of the vibrating particles (see p. 70).

offered in the last chapter, and it is only necessary to suggest a slight amplification of the theory on one or two points.

As already intimated, the waves which interfere are not to be regarded as destroying one another, but merely as amalgamating to produce new waves so modified as to be unable to produce light.

The approximate equality in width of the light and dark rings in Newton's experiment points to the conclusion that of the different relative positions of the two sets of similar waves given by reflection at different points from the two surfaces of a film of *graduated thickness*, including all cases ranging from that of coincidence of rank of the two sets of waves to the case in which one set is exactly half a wave-length behind the other, about one half produce amalgamated waves in which the waves of one set join with those of the other to form united waves of similar wave-length of double strength, and the other half produce compound waves, in which the motions originating from one set continue to fall between those originating from the other.

And lastly, the fact that interference occurs only when a film is *very thin* supports our conclusion that groups of waves of the same kind travelling in the same direction are successive, and not continuous; the succession being a broken one, and group following group in inconceivably rapid succession. For, if this is so, we see that the waves of any particular group reflected from the second surface will not be superimposed on those reflected from the first *unless they reach the last-named surface while the reflection of this group of waves from this surface is still going on.*

The iridescence of finely striated surfaces is very similarly explained. One of the best instances of it is presented by what are known as "Barton's buttons," articles once employed for ornament, whose faces are polished metal

stamped by a die of hardened steel, engraved with a pattern made up of small areas ruled in different directions with close equidistant parallel lines.*

Let the accompanying diagram represent a highly magnified section of such a striated surface with its adhering stratum of condensed ether, from which we have concluded the reflection takes place (p. 222). The surface of this stratum will evidently be undulatory, and, selecting similarly placed points in each of the similar depressions shown upon our section, it is manifest we can draw a succession of parallel normals inclined at any angle we please to the general direction of the surface; this angle being regulated by the position of the similar points. And from these normals we can determine the direction of parallel

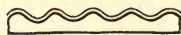


Fig. 22.

rays of light after reflection from the similarly situated points.

Now, if the striation is sufficiently fine, the same identical group of waves will suffer reflection in more than one of the furrows, and the waves reflected at any one of the similarly situated points will be slightly in advance of the waves of the same group reflected at the point next adjoining on one side, and slightly behind those reflected at the point next adjoining on the other side; this difference in rank will, moreover, be precisely regulated by the positions on the surface of the similarly situated points. The resemblance to the conditions which we traced in the case of reflection from the two surfaces of thin films is evident, and the theory of interference already placed before the reader will we submit apply in the present case.

Striated surfaces, such as just described, have been used

* Mother o' pearl has been proved to owe its play of colours to fine striations analogous to those of "Barton's buttons."

for the purpose of calculating the actual wave-length of ether vibrations.

Diffraction.

The name “diffraction” has been applied to certain phenomena which we shall endeavour to show are due to the combined action of refraction and interference. Two typical instances will be dealt with.

Diffraction bands are produced by allowing white light whose rays are all parallel—as, for example, sunlight from a small portion of the sun’s disc—to pass through a *very narrow straight slit* ; a screen placed to intercept the rays

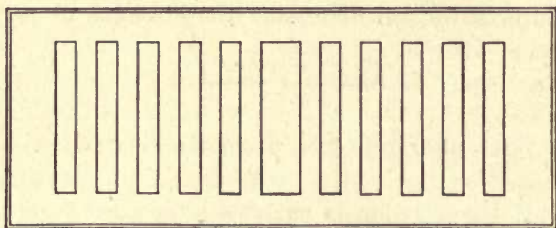


Fig. 23.

then displaying a rectangle of white light, much wider than the width of the slit, bordered on each side with coloured fringes, and the narrower the slit the wider this rectangle and the attendant fringes. If the light be monochromatic, we get a remarkable series of bright bands separated by dark spaces ; the central band being widest and by far the brightest, and those on each side of less and less brightness as we travel from the central band (see fig. 23). The extreme red end of the spectrum gives the *widest* bands separated by the widest dark spaces, and both the bands and the spaces are narrower the nearer the place of a selected colour is to the violet end of the spectrum. The central white rectangle with coloured

fringes, produced when we use white light, is therefore seen to result from the superposition of a complete succession of these series differing from one another, in the way just stated, according to the place of the light producing them in the spectrum.

As to the phenomenon being partly due to refraction:—

We see that, if, as previously concluded, the free surfaces of bodies have adherent to them thin films of highly-condensed unimolecular ethers the density of which diminishes outwards from the body (p. 50), any very narrow slit in a solid plate, or film, will be filled by a medium of graduated density, the greatest density being found next the solid edges of the slit, and the least centrally between the edges (see fig. 24, in which a magnified section of a slit is represented, the gradation of ether density being depicted by means of dotted lines).

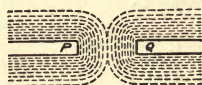


Fig. 24.

A medium of this kind will evidently produce refraction of the following peculiar kind:—Since light is deflected towards the perpendicular on passing obliquely into a more-refracting medium, and from the perpendicular on passing into a less-refracting medium, the light passing through the slit will be more and more refracted the nearer it passes to the sides, so that though when it enters its rays are all parallel, when it emerges they will be divergent,—only the light which passes precisely along the axis of the slit maintaining its original direction. The courses taken by the various groups of ether waves composing the light, in any plane perpendicular to the length of the slit, will therefore be represented by some such system of curves as is shown in the accompanying diagram (fig. 25).

Finally, as to the manner in which refraction of this kind causes interference, we observe that, since the

paths followed by the ether waves have more rapid curvature the further they lie from the straight central path, the ether waves following any one of these paths will *gain in rank of advance* on the similar waves of the same group which are next them *nearer the central path*; and moreover *this gain will be greater the further the paths are from the central path*. Thus, in our diagram, paths of equal length are marked off by the two lines AB , CD , and it is evident that the more distant a path is from the straight central path the more obliquely the line CD intersects it.

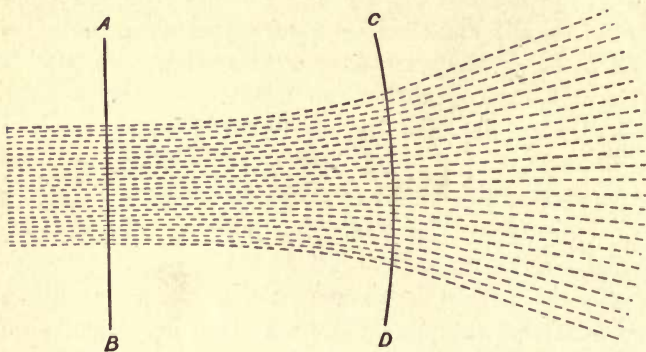


Fig. 25.

The condition of things is therefore much the same as in the cases of interference due to minute striations, above treated, in which adjoining vibrations were seen to fall one behind another; and the alternate bright and dark bands of the phenomenon before us are naturally explained if we suppose that modified systems of waves, resulting from the peculiar refraction which has been explained, produce light when vibrations adjoining in the same rank are approximately synchronous,—*i.e.*, when the value of the difference in rank is approximately some integral multiple of a wave-length;—and do not do so when they

are not,—i.e., when this value falls about midway between two such multiples.

The only condition requisite for us to perceive diffraction in cases when light grazes the boundary of a dense body is that excessive light be shut off from the retina, which otherwise becomes unconscious of feeble rays. Tyndall notices diffraction produced by looking at a street lamp through the meshes of a handkerchief. The phenomenon may too be seen as produced by the eyelashes, when the eyes are half-closed in bright sunshine.

The second typical case of diffraction, which we now propose to deal with, is that of *diffraction spectra*, as they are called, produced by the use of an instrument known as a "*grating*."

A grating is a piece of glass ruled with parallel equidistant scratches which are so close together that some hundreds, or even thousands, are contained in a width of one inch, or it is a photograph of such a system of parallel scratches. When it is held between the eye and a slit through which a bright light is passing, in such a manner that the rulings are parallel to the slit, a succession of complete spectra ranged on both sides of the image of the slit are visible.

As to how refraction of a nature to account for the phenomenon is produced we observe :—

The regular gradation of density of the highly-condensed ether adherent to the surface of the glass (p. 50) must, according to our arguments, be affected by the presence of the series of minute hollows, or, in the case of a photograph, of the series of minute ridges, the effect of this gradation of density in both cases extending over the clear spaces between the striations; consequently there will be in each of these minute spaces or slits through which the light passes, a medium of graduated density. The parallel rays which pass through any one of these

spaces will therefore be refracted in the way already explained, and spread out like a fan, and from every space between the striæ rays of all colours will be diverging in planes perpendicular to the direction of striation.

The case is therefore a parallel one to that already referred to, of rays diverging from a striated reflecting surface (p. 249)—(indeed a diffraction spectrum can be obtained from such a surface if the scratches be finely ruled),—and we see that the predominant colour seen in looking at any particular part of a grating will be that whose waves are of such a length that the angle at which they leave the grating gives a difference in rank of adjoining vibrations, of a wave-length, or an integral multiple of a wave-length ; for this will make the vibrations adjoining one another in the same rank synchronous at any given atom they encounter.

The regular order of the colours according to their wave-lengths, and the succession of spectra are evidently direct consequences of this.

The usually received explanation of the phenomenon, which closely resembles that just given, has enabled a calculation of wave-lengths to be made in terms of the distance apart of the striæ and the direction after passing the grating of the rays of a particular colour. For this the reader is referred to the ordinary treatises.

In connection with the theory just put forward, that diffraction is really due to refraction, the excessive sensitiveness of gratings to pressure, or inequalities of temperature, may be noticed. Mr. C. A. Young speaks of a grating upon a plate fully three-eighths of an inch thick and only $3\frac{1}{2}$ inches square whose definition was materially modified by the pressure of a single ounce upon one corner, and the definition actually destroyed by a weight of a quarter of a pound. *

* *Nature*, No. 586, p. 282.

As an interesting example of diffraction we have the familiar fact that the central spot of the shadow of a small circular disc cast by rays diverging from a distant point in its axis is as brightly illuminated as if the disc were absent.

Colour Produced by the Presence of Dust or Small Particles.

Brücke and Tyndall have directed attention to the fact that very minute particles reflect light belonging to the violet end of the spectrum more completely than that belonging to the red end, producing when illuminated a sky-blue colour, and have argued from this the presence around the earth of minute particles producing by selective reflection of this kind the blue colour of the sky.*

The following explanation of the phenomenon is here suggested :—

We have concluded that the surface at which refraction occurs is not the actual molecular surface of the refracting body, but that of a highly-condensed stratum of unmolecular ether present at this surface, and from this it would follow that when particles of matter are infinitesimal their refracting surfaces are always *curved surfaces of high convexity*. And it is evident from a consideration of the law of refraction, that if the convexity of the surface of a more-refracting medium be very great indeed, waves *of the same group* entering the medium will find the space allotted to them become very contracted, and that *the more refrangible the waves the greater the contraction they will experience*.

Now we have argued that the partial reflection of ether waves which occurs at the surfaces of transparent media is caused by the space allotted to the transmitted waves being contracted through refraction ;—those particles of ether in each wave which are unable to pass into the more-refracting medium going to form a reflected wave (p. 226) ;

* As to polarization of light of the sky, see p. 285.

and therefore we see that the greater contraction of the space allotted for transmission experienced by the more-refrangible waves, which has just been argued, will cause these waves to be transmitted in a less proportion than less refrangible waves, and consequently to be more reflected. The fact that the light transmitted through media containing small particles exhibiting the phenomenon just referred to is yellowish or reddish, like the transmitted colours of sunset, is consistent with this explanation.

This closes our examination of the phenomena of colour due to the form and not to the composition of bodies.



CHAPTER XXIII.

COLOUR—PHOSPHORESCENCE AND FLUORESCENCE— TRANSPARENCY.

WE propose to consider in the present chapter the various sources of the distinctive colours of bodies—in other words the causes of the prevalence of waves of certain wave-lengths in the light coming from particular groups of atoms.*

These sources are, it is submitted, three in number, viz. :

1. A greater facility of transmitting some ether waves than others possessed by some molecular masses, causing them to reflect larger proportions of the waves transmitted with less facility.

2. The modification and destruction, so far as light-giving power is concerned, of certain of the waves traversing a body, occurring through their amalgamation with similar waves set up by the explosion of some of the primary atoms composing the body, and this explosion being chiefly due to the action of the incident waves.† The colour of the body is in this case due to the *unaltered* incident waves, transmitted or reflected as the case may be.

3. Explosion of the atoms of a body considerable enough

* Colour in its physiological aspect is considered subsequently.

† So far as the waves set up are due directly to the action of the incident waves, this is the principle on which we have already explained Fraunhofer's lines.

for the ether waves produced to determine directly the colour produced.*

The first-mentioned of these is, it is suggested, the source of the distinctive colours of the various metals, the least transparent of all bodies. Thus the preponderance of yellow in light reflected from gold is probably due to the more ready penetration of this metal by light of the complementary colour; and this is to some extent countenanced by the fact that the transmitted colour of unbeaten gold is violet and of beaten gold green; the matter is however obscure.

The second source of colour which is above suggested we connect with the phenomenon ordinarily called *absorption*; a power which most substances possess of suppressing some particular kinds of light, so that the light they transmit when illuminated, whether that evidently passed through them, or that which is reflected after entering them to a greater or less depth,† is complementary of this suppressed light. It has been found that nearly all the objects around us owe their distinctive colours to this power of so-called absorption.

The reason why, in cases of colour thus produced, the ether waves which suffer modification have so wide a range of wave-length, and are not merely of the kind which the atoms of the body if exploding quite freely would produce, as in the case of Fraunhofer's lines, appears to be that the highly-condensed state of the atoms modifies their explosive effect, so that the waves they produce have a wide range of wave-length; a suggestion which will receive abundant corroboration when we deal with the subject of Spectrum Analysis.

* Colour thus produced will evidently be due solely to waves set up by the exploding atoms of the body *which have not been deprived of light-producing power by amalgamation with incident waves.*

† The transparency, or penetrability of bodies by ether waves will be considered presently.

The supposition that some of the ether waves of the light falling upon a body produce atom explosion in it productive of similar waves, is in harmony with our previous arguments, and further, as evidence of the occurrence of atom explosion in bodies exposed to light we have the following :—

(a) It is found that absorption is always accompanied by the liberation of heat, and heat will in the sequel be argued to be an evidence of molecule destruction (p. 309).

(b) The phosphoroscope devised by Becquerel has shown that nearly all bodies shine with phosphorescent light for a shorter or longer time,—sometimes but a mere fraction of a second,—after having been strongly illuminated ; a fact which, if, as we have argued, light results from atom explosion, proves that a condition of atom explosion is produced by the incidence of ether waves, and continues for a short time after their discontinuance.*

(c) The gradual loss by bodies of their characteristic colour, so familiar to us as the *fading* of colour, and due to the survival of ether waves of kinds formerly “absorbed,” may probably in many cases be regarded as a wasting effect of the process of absorption, due to particular kinds of atoms becoming gradually fewer at the surfaces exposed to the incidence of the illuminating waves ; † and it accords with this view that fading is more rapid the stronger the light.

(d) The molecular changes produced by light, indicated by its destructive effect in rotting fabrics, we should suppose arise from molecule destruction. And molecule

* Phosphorescence is considered further, p. 260.

† Rapid alterations of colour must, however, be attributed to chemical changes. In living organisms, *e.g.*, flowers, we may surmise that fading is prevented or retarded through fresh atoms being supplied by the circulatory changes incident to a state of life.

destruction will in the sequel be argued to be the first step in the chemical changes produced by light.

In connection with the above theory of absorption we may refer to the following familiar experiment as furnishing evidence that molecular masses when placed in conditions favourable to atom explosion emit ether waves of the kinds which our theory of absorption requires us to suppose they are ordinarily emitting, and as the result of the emission of which they have their characteristic colour.

If we take a piece of stoneware of a black and white pattern, and heating it to redness view it in the dark, we find that the black of the pattern shines much more brightly than the white, so that a curious reversal of the pattern is produced. From this and other kindred experiments the law has been deduced *that bodies when cold absorb the rays which they give out when hot.**

The third source of colour we have suggested is, it is submitted, the source of all cases of *the emission* of coloured light by molecular matter, including all forms of *incandescence*, from that accompanying the violent chemical action of combustion to the softest electric glow, and also all instances of *phosphorescence* and *fluorescence*.

Several facts relating to these different phenomena are in harmony with this theory.

Thus the very fact that light so commonly accompanies combustion, viewed in connection with the arguments offered in the sequel that the heat and chemical change of combustion both result in all cases from the expansion

* An instance of this law as applied to ultra-red rays is found in the fact that if we pass the rays from heated rock-salt through a plate of cold rock-salt, this substance, which is generally found very transparent to rays at the extreme red end of the spectrum, "absorbs" a very large proportion of such rays,—a moderately thick plate disposing of at least three-fourths of them.

of atoms to the unimolecular state, favours this view as regards all cases of ether waves produced during combustion ; the fact already referred to, that the colour of incandescent vapour is quite characteristic, so that when analysed by a prism its ether waves are found to have certain definite places in the spectrum according to the kind of matter rendered incandescent, furnishes the strongest evidence in the same direction. And we may further cite, as giving some additional support, the fact that flames conduct electricity ; for we may suppose that in this case the ether continuity, which we have concluded is necessary that conduction of electricity may occur (p. 68), is due to the separation or assortment of *newly-liberated ethers* into continuous masses of each kind.

Again, the fact that electricity, whose power of producing the destruction of primary atoms has been already referred to (p. 122), commonly produces light when denied free conduction, goes far to justify the reference of all light electrically produced to the explosion of some of the primary atoms of the dielectric ; and we have further the important corroboration afforded by the fact that the colour of the light produced is found in a multitude of instances to depend on the kind of molecular matter present at the place of its production. Thus the colour of the electric spark in air is bluish ; in nitrogen it has a bluish purple tinge ; in oxygen it is white and less brilliant than in air ; in hydrogen crimson-coloured ; in carbonic acid greenish.

When the discharge is through highly rarefied gases very beautiful luminous effects are presented. In an exhausted tube containing *rarefied air* we have, when the discharge passes, a luminous sheaf of purple colour extending from the positive ball terminal to within a short distance of the negative ball, which latter is surrounded by

a bluish glow.* If other attenuated gases are used other colours are obtained. If before exhausting, a little alcohol, or other volatile liquid is introduced, we obtain a series of transverse bright bands separated by dark spaces, and indeed if the exhaustion be carried sufficiently far, as in what is known as a Geissler tube, which contains some gas in a very attenuated state and has electrodes of platinum wire, the bright bands are produced without the presence of the volatile liquid (see fig. 6, p. 110).

Some reference has been made already to the causes of the molecular condition which these appearances indicate (p. 111), and some further reference will be made to these causes hereafter; what we note here is that the phenomena referred to support our contention that the light produced by the electric discharge is due to concerted atom explosion, the precise nature of which depends partly on the kind of atoms present, partly on the conditions in which these atoms are placed, *and that these phenomena indicate that the unimolecular ethers are by themselves absolutely non-luminous.*

As further evidence that this is so we may mention the fact that when an extreme exhaustion of a glass vacuum tube has been reached certain parts of the interior of the tube become luminous during the passage of an electrical discharge, *the light emitted being green when German glass, blue when English glass is used.* The portion of the glass rendered luminous depends on the form and position of the negative terminal, but, to show how completely the phenomenon depends on the molecular condition of the glass, we have the fact that use deadens the phosphorescence.†

An observation made by Mr. Crookes on the effects in a

* Effects in nature analogous to these luminous vacuum effects are seen in the case of auroras.

† The extent of the falling off in luminosity is scarcely perceptible at very high exhaustions, and there is a partial recovery when the glass is allowed to remain quiescent for a while.

body of repeated excitation to phosphorescence by the electrical discharge may be given in this connection. He says, "After long experimenting with chemically pure alumina precipitated from the sulphate, a curious phenomenon takes place. When sealed up in the vacuum two years ago it was snow-white; but after being frequently submitted to the discharge for the purpose of exhibiting its brilliant phosphorescence, it gradually assumes a pink tinge, and on examination in sunlight a trace of the alumina line can be detected. The repeated excitation is slowly causing the amorphous powder to assume a crystalline form.*

Mr. Crookes has also noticed the coincidence of spectra of the phosphorescence produced by the solar rays in the phosphoroscope with the corresponding spectra of the phosphorescence obtained in high vacua.

Substances which are readily excited to phosphorescence by being illuminated shine with great splendour when subjected to the negative discharge in a high vacuum.

If, as we have argued, the luminosity in vacuum tubes is due to atom explosion induced by the presence of the unimolecular ethers of the discharge, the following account of the effect of electrical shadows† on this luminosity, quoted from a paper by the late Mr. Spottiswoode,‡ appears to throw some light on the nature of the distribution of the unimolecular ethers in a vacuum tube.

"The two terminals of a Holtz machine were connected in the usual way with the two terminals of the tube, so as to produce a stratified discharge. A narrow strip of tinfoil, or a wire was stretched along the tube opposite the column

* Paper read before Royal Society, May 19, 1881, by William Crookes, F.R.S.

† See p. 100.

‡ "On Stratified Discharges. VI. Shadows of Striæ," by William Spottiswoode, P.R.S., see *Nature*, No. 611, p. 254.

of striæ. The positive terminal of a second Holtz machine (in practice we used for this purpose a Töppler machine) was connected with the tinfoil, and the negative terminal with one (either) terminal of the tube. An air spark, or interval across which sparks could pass was interposed in the part of the circuit between the machine and the tinfoil. The effect of this arrangement was this :—In the interval between two sparks the tinfoil and tube became charged like a Leyden jar ; the tinfoil being the outer coating charged positively, and the gas inside serving as the inner coating, charged negatively. When the spark passed across the interval mentioned above, the jar (*i.e.*, the tube) became discharged, and the electricity previously held bound on the two coatings was set free. When the first (say the internal) machine was not working or when it was disconnected, *i.e.*, when no regular discharge was passing through the tube, then, whenever a spark passed at the second (or ‘external’) machine, a negative discharge with its accompanying Crookes’ radiation took place from the inside of the tube next the tinfoil, and the opposite side of the tube became covered with a sheet of green phosphorescence (the tube being of German glass). When however, other things remaining as before, a discharge from the internal machine was sent through the tube, and a good stratified column was produced, it was found that the green phosphorescence was entirely cut off from the parts of the tube opposite to the striæ, while on the parts opposite to the dark spaces it remained, in the form of phosphorescent rings, as brilliant as before. It may be added that where, as is sometimes the case, through greater exhaustion, the striæ became feebler in illumination and less compact in appearance the shadows cast by them lost proportionately in sharpness of definition and in completeness of extinction of the phosphorescent light.”

As evidence that the gentler kinds of phosphorescence,

including fluorescence (which is phosphorescence due to the incidence of light from some external source that ceases immediately after this latter is withdrawn), are due to the cause suggested, we may notice the significant fact observed by Sir John Herschel, that a beam of light is, by transmission through a solution of sulphate of quinine, though not sensibly weakened in luminous power, yet quite robbed of its power of producing fluorescence, all the fluorescence observed in the solution proceeding from a thin stratum adjacent to the surface acted upon by the stimulating rays. For the natural conclusion appears to be that, in harmony with one of our previous conclusions (p. 201), atoms are more readily exploded by ether waves of the wave-length of those they themselves produce; that the ether waves of the fluorescent light, and of any ultra-violet rays also being emitted, have therefore the same wave-lengths as have such of the ether waves of the incident light as are concerned in producing the atom explosions to which they are due, and that the amalgamation of the former waves with the latter, in the way explained above, accounts for the absorption by the solution of such of the incident waves as are capable of producing the fluorescence.

As evidence of the occurrence of molecule destruction in phosphorescent bodies, we may cite the photo-electric phenomena which they exhibit when exposed to light,* for these, according to our theories, are due to ether liberation (see p. 183). Crystals long exposed to light are weakened in their photo-electric sensibility.

Perhaps the occurrence of phosphorescence in organic bodies, sometimes observed, may also be regarded as evidence in the same direction; for in the case of living organisms, we have a probable origin of atom explosion in the rapid molecular changes concerned in producing

* Observed by Herr Haeckel.—*Nature*, No. 580, p. 133.

very rapid growth, or metamorphosis, or very swift movement, or frequently recurring waste and recuperation ;* and where phosphorescence is associated with decay, as in the familiar examples of Will o' the Wisp, and dead fish, atom explosion is, according to our theories, a necessary accompaniment of the molecular changes involved.

Further, we may surmise, in this connection, that the astringent property possessed by many vegetable substances whose solutions exhibit considerable fluorescence,—in other words, the power possessed by such bodies of checking molecular change in the delicately adjusted matter of organic bodies,—is due to a continual liberation of un-molecular ethers within them sufficient to effect an alteration of the ether conditions prevailing about the atoms of bodies to which they are applied.

The fact that the light of phosphorescence belongs to the violet end of the spectrum, probably indicates that phosphorescing substances are liberating an excess of positive ether (see p. 312).

The close connection between phosphorescence and the incandescence of combustion seems to be indicated by the behaviour of phosphorus. This substance is, in its normal condition, on the border land between phosphorescence and combustion, the slightest inciting force commonly sufficing to carry it over the border ; its normal condition may indeed be regarded as a tame kind of combustion, chemical change accompanying the phosphorescence.

Phosphorescence, like combustion, is in some cases produced by friction. A familiar instance of this, known to

* These suggestions will be better understood after the application of the theories of this treatise to a few of the phenomena of biology has been considered. Phosphorescence of the retina of the eye, seen particularly in some of the lower animals, will be argued to be an instance of association of the phenomenon with frequently recurring waste and recuperation.

every schoolboy, is the production of a glow of light by rubbing two flints together.

Unlike the case of colour due to absorption, in which the coloured light coming from a body is the residuum of the illuminating rays after the withdrawal of the rays "absorbed," and where, therefore, this colour depends on the colour of the illuminating rays (see p. 258), the colour of phosphorescence is, in most cases, sensibly constant in the same substance, whatever the colour of the stimulating rays,* and we conclude from this that the phenomenon is due to certain atoms in a body being so conditioned as to pulsate very readily in response to the fluctuations of ether waves which encounter them, the explosion of one kind of these atoms involving the explosion of the others.

Prof. G.G. Stokes has called attention to a fact analogous to the fading of colour alluded to above, which to some extent favours this conclusion. He finds that diminished excitability to phosphorescence follows continuous illumination. Perhaps, however, this is more likely to be due to changed ether conditions produced by the molecule destruction incident to phosphorescence than to any exhaustion of the supply of the particular atoms producing phosphorescence *exposed to the incident light*; it may be partly traceable to both causes.

A familiar fact favouring the suggestions made above,

*This is only an approximate truth. Capt. Abney has shown that a phosphorescing body is differently acted on by waves of different wave-length; *e.g.*, when the spectrum is allowed to fall on an excited surface of Balmain's paint the blue rays enhance the violet phosphorescent light while the red rays extinguish it. Capt. Abney has further shown that there is a series of "octaves" in the blue end of the spectrum which refuse to quench violet light.—*Nature*, No. 641, p. 355.

And Prof. G. G. Stokes has observed the similar fact that sunshine and artificial light excite different phosphorescence in the same substance.—*Nature*, No. 658, p. 142.

that phosphorescence is due to the peculiar conditions of certain kinds of atoms in the phosphorescing mass, is that ether waves of very various wave-lengths are found competent to stimulate similar phosphorescence in solid and liquid substances. Thus some substances, as sulphate of quinine, are even stimulated to phosphorescence by dark rays beyond the violet end of the spectrum, indeed, generally, those bodies which exhibit phenomena of fluorescence have a faint nebulous light when held in the ultra-violet rays, as well as when held in the rays of the visible spectrum.*

In conclusion, some facts respecting fluorspar may be quoted to show how completely the colour of the phosphorescent light of a body, as well as its own proper colour, depend on the ether conditions surrounding its atoms;—that different ether conditions produce differences in the proportions exploded of the different kinds of primary atoms. Thus fluorspar which has its colour readily deepened by the application of heat, so that it is very customary before its use for ornamental purposes to exchange its natural blue for an amethystine tint by this means, loses both its colour and its phosphorescence if sufficiently heated.†

The stability of the different tint acquired by fluorspar when gently heated must be regarded as an indication of the permanence of the changed ether conditions when once brought about by the application of heat.

The normal colour of fluorspar is partially restored by

* A similar power is possessed by the ultra-red rays. Thus if the beam from the electric lamp be concentrated by a suitable reflector, and all the luminous rays be then cut off by a glass cell containing a solution of iodine, the remaining ultra-red rays are still adequate to produce incandescence of a sheet of platinum.

† It will be argued in the sequel that an increase of temperature is ordinarily caused by an increase in the quantity of negative unimolecular ether present (see p. 315).

an electric discharge, which we have concluded is a flow of the unmixed ethers.

Transparency.

From the preceding arguments we see that opaqueness of homogeneous matter to light must be attributed to one of two causes.

(a) Rigidity of the particles, such as we have concluded produces great reflecting power in the case of the metals.

(b) Modification of the incident ether waves caused by interference between them and ether waves due to atom explosions which they set up within the mass.

The fact that crystals, some of which are the hardest of all bodies, are often so highly transparent is in harmony with the supposition that they are examples of the cellular solid state and consist of aggregations of infinitesimal cells (p. 28); for it is readily seen that, a to and fro movement of the septa or cell walls being possible, ether waves which are sufficiently minute and, at the same time, sufficiently violent, will be able to pass from the partly expanded ether of one cell to the partly expanded ether of another without rupture of the cell walls.

We may suggest that transparency of liquids is partly due to the presence within them of the unimolecular ethers, to whose increased liberation the liquid state has been attributed, and it is possibly owing to this that water is more transparent than ice, and oil more transparent when fluid than when congealed.

We may notice here, as a link between transparency and non-conduction of electricity, that we connect both phenomena with a high mobility of the ether particles of the body in which they are observed, and, in harmony with this, that bodies which are transparent to light

are insulators, or non-conductors of electricity, and that conductors of electricity are always opaque to light. The remarkable researches of Prof. Graham Bell have recently shown that even *ebonite*, an insulator which is most opaque to the rays of the visible spectrum, is transparent in no small degree to some ether waves outside it.

CHAPTER XXIV.

DOUBLE REFRACTION AND POLARIZATION.

WHEN a crystal of Iceland spar is laid upon a page of a book it transmits a double image of each letter seen through it, and if the crystal is turned round while still in contact with the paper, one image revolves around the other which remains unmoved, and the image which revolves appears further from the eye than the other image. The property of double refraction of which this is a striking instance is possessed in a lesser degree by many other crystals which, like Iceland spar, do not belong to the cubic system.

To exhibit the phenomenon known as polarization, two thin slices of tourmaline cut parallel to the crystal axis are generally used. This crystal does not exhibit double refraction so strikingly as Iceland spar does, because it has the property of very speedily quenching the less refracted ray, so that unless a very thin slice indeed is used, but one ray emerges whose index of refraction is variable. When the two slices are laid flat upon each other, and so that the axis of the one crosses the axis of the other at right angles, no light passes where they cross, but as one of the slices is turned round upon the other and the angle between the axes diminished, light begins to pass, until, when the axes of the two crystals become coincident in direction, the combination of the two slices is as transparent as a single slice of the double thickness

would be. Three positions of the tourmaline are depicted in the accompanying figure.

The immediate deduction from the foregoing facts is that transmission through some crystals gives to waves of light a distinctive *polarity* of a certain kind having reference to the direction of the crystal axis, and that the two rays into which a single ray is found divided after transmission have this polarity in directions at right angles to one another, and further that the particles within the crystal whose motions convey light move faster in rays whose polarity has one direction, than in those whose polarity has the other direction.

The theory of double refraction and polarization by transmission offered in this treatise is:—

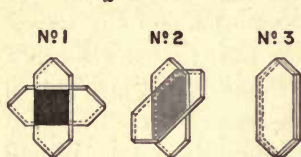


Fig. 26.

(a) That in those crystals which exhibit these phenomena the cell walls, or septa, whose presence we have concluded to be characteristic of the cellular solid state (p. 28), are

symmetrically situated with respect to the crystal axis, and that their arrangement is such that ether motions communicated from cell-interior to cell-interior through the flexible cell walls experience different degrees of resistance and retardation according to the inclination of their path to the crystal axis; in some crystals the retardation being *greatest* in the direction of the crystal axis, in others *least*.

(b) That when ordinary ether waves pass into such a crystal the effect of the different degrees of retardation experienced by moving ether particles, according to the direction they are taking, is that each series of fluctuations of alternate radiation from and return to a prism-axis, found in ordinary ether waves (p. 203) furnishes two series of modified fluctuations *having different velocities of propagation*, one series springing from the portions of the original

series found in opposite quadrants about the prism-axes whose bisectors are at right angles to the crystal axis, the other series from the portions found in the remaining quadrants. Thus, if fig. 27 represents a transverse section of a few of the prism-shaped surfaces of maximum ether condensation in a group of ordinary ether waves made at the surface of the crystal *held with its axis horizontal*, it is supposed that one series of modified fluctuations will spring from portions of the original fluctuations occurring within angles such as $m \Delta n$, $p \Delta q$, the other series from those occurring within angles such as $m \Delta p$, $n \Delta q$.

(c) Finally, that the paths of the moving ether particles in one series come to be mainly, though not exclusively, in planes at right angles to the crystal axis, while those of the moving ether particles of the other series similarly approximate to the plane direction perpendicular to this containing the crystal axis.

We shall now bring forward arguments in support of this theory.

And first as to the section of it we have marked (a) there is abundant evidence in the different conductivity of uniaxal crystals in different directions for heat, and also for electricity, as well as in their optical properties, to prove the existence of symmetry of arrangement of their particles with respect to the crystal axis (see p. 183), and the supposition that the arrangement is such as to involve more retardation of ether motions occurring in some directions than of those occurring in others is evidently quite in harmony with the conclusion that crystals have a cellular structure of the kind supposed.

Next as to the sections of the above theory which we have marked (b) and (c). We will take the simple case of

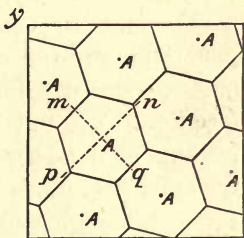


Fig. 27.

ordinary light falling vertically on a plate of double refracting crystal, cut parallel to the axis, the ether retardation being least in the direction of this axis,* and endeavour to show that each group of ordinary ether waves, such as we have described, will, in traversing such a crystal, be separated into two modified groups, one of which will come to have its vibrations almost solely in planes at right angles to the crystal axis, the other almost solely in planes in the direction of this axis, drawn perpendicular to the crystal surface.

The following is the line of argument we take for this purpose :—We have said that where ether waves are traversing an isotropic medium each of the surfaces of maximum ether condensation is equidistant from its two generating centres, or axes, and therefore bisects at right angles transverse lines drawn from one axis to the other (see fig. 27). But in the case of waves traversing a medium of non-isotropic crystal the different velocities of the ether vibrations in different directions will cause these surfaces, though still each equidistant from its generating axes *as measured by time*, to be no longer equidistant as measured by actual length. Our first step is to trace the positions of surfaces of maximum ether condensation as presented *immediately within* the crystal.

Now we suppose that the relative velocities of ether particles similarly projected in different directions within the crystal are represented by radii drawn in these directions to a spheroid whose principal axis has the direction of the crystal axis and whose principal and subordinate axes are in the ratio of the velocities of particles similarly projected in the direction of the crystal axis and in planes at right angles to this axis respectively.† And upon this

* Such are called negative crystals.

† In the case of a *positive* crystal the spheroid referred to will be an *oblate* spheroid, in the case of a negative crystal it will be a *prolate* spheroid.

supposition it is evident that, since in the case supposed the relative position of the prism-axes continues absolutely unchanged by their entry into the crystal because there is no refraction, the locus traced by each surface of maximum ether condensation in a plane just within the crystal, and parallel to its surface, is the locus of the points of intersection of pairs of equal and similar ellipses, whose centres have the relative situation of the points of intersection of the two generating prism-axes with the plane of the crystal surface, and whose major axes are all horizontal, and bear to their respective minor axes the

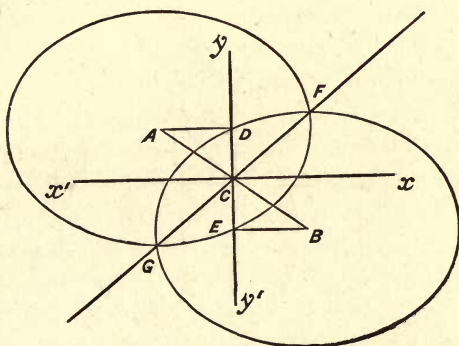


Fig. 28.

ratio of the two limiting velocities within the crystal which are above referred to.

To ascertain these required loci we have to solve the following problem :—

Problem—To find the locus of the points of intersection of pairs of identical ellipses, which have their centres at two given points, all the ellipses having their respective axes parallel, and the lengths of the major and minor axes of each pair having a constant ratio :

Let A, B (fig. 28) be the two given points. Bisect AB in C, which from considerations of symmetry will evidently

be one point upon the locus. Then if any pair of identical ellipses drawn as prescribed, intersect each other in two points F, G , the points F, C, G will lie in a right line, which is the locus required.

For let Cx a horizontal line, and Cy a vertical line, have the directions of the major and minor axes respectively. Draw AD, BE perpendicular to ycy' , these lines being evidently equal to each other. And then let a plane be conceived, drawn through ycy' to make an angle with the plane of the diagram, whose cosine is the given ratio of the minor and major axes, and on this plane project

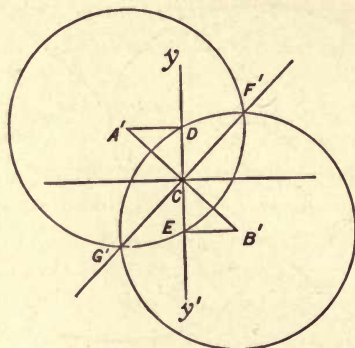


Fig. 29.

the lines we have drawn on the original plane by a series of perpendiculars dropped from these lines on to the plane thus conceived.

Then the nature of this projection is evidently such that the projections of all ellipses drawn as prescribed will be circles, and since it is evident from a very simple geometrical consideration, that the locus of the points of intersection of pairs of these circles is a straight line drawn through the intersections of any pair, it follows that the locus of the intersection of the ellipses of which the circles are projections, is also a straight line drawn

through the points of intersection of any pair of ellipses.

To exhibit diagrammatically, in accordance with this conclusion, the nature of the disposition of the prism-shaped surfaces in some group of ether waves passing into a crystal in the manner supposed :

Let A, A, A , etc. (see fig. 27, p. 273), represent the intersections of some of the prism-axes of the group with the surface of the crystal laid with its axis horizontal.

Project these intersections in the way above described, the plane of projection cutting the original plane in $y y'$ (this is a simple proceeding, as every vertical length in the original is represented by an equal length in the projection, and every horizontal length by a length which bears to it the given ratio of the two velocities). Let $A' A' A'$, etc. (fig. 30), represent the resulting projections. Then, since the projections of all ellipses drawn as prescribed will be circles, *the projections of the loci of the intersections of pairs of these ellipses (which loci we have seen are those traced by the surfaces of maximum condensation in a plane just within the crystal parallel to its surface) will be straight lines drawn to bisect at right angles lines joining the projections (A') of the wave centres.* When these bisectors have been drawn to meet one another (see fig. 30), we can, by a simple method of proportions, taking every vertical length the same, and every horizontal length in the inverse of the given ratio of the limiting velocities, construct the loci themselves (see fig. 31).

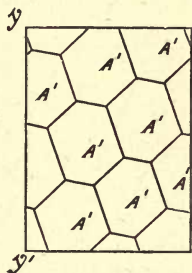


Fig. 30.

Finally, to show that each group of ordinary ether waves will, in addition to experiencing this change, be presently separated into two modified groups in the way stated :—

While it is evident that the first set of similar fluctua-

tions, radiating abreast of one another from the various prism-axes of one of the wave groups after its entry into the crystal, will have the same rank of advance at all the prism angles ; these angles being all similarly situated with respect to the three prism-axes nearest to them ; we see that the advance of these fluctuations will be less rapid along the prism surfaces in which the most retarded radiations meet, than along those in which the least retarded radiations meet ; and that, as succeeding pulsations follow one another, an increasing difference of rank of advance of different portions of the fluctuations will be exhibited.

It is difficult to trace the precise modification of a group of waves which must result, but it is evident that since the radiations occurring in two opposite quadrants about each prism centre (as $m \Delta p$ and $n \Delta q$, fig. 27, p. 273) are met by neighbouring radiations *before* those occurring in the remaining two quadrants (as $m \Delta n$ and $p \Delta q$) are thus met, the por-

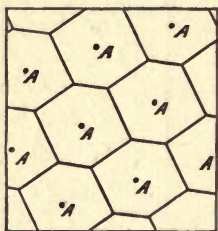


Fig. 31.

tions of an ether wave in one pair of quadrants, will, after the first pulsation, be unsupported by the portions in the other pair, and will therefore, *instead of concentrating at a prism-axis, have a parallel motion of their particles, each particle moving approximately in a plane parallel to the plane of incidence drawn bisecting the quadrant* ; and we readily perceive the result will be the division of each wave group into two modified groups similar to one another, one of which has the bulk of its ether particles moving in planes at right angles to the crystal axis, the other in planes containing the crystal axis, and the concentrations in each taking place along parallel planes, probably of small extent, instead of as in the ordinary ether waves.

Similar reasoning would apply to other more complex cases.

The plane drawn in the direction of propagation of a polarized ray at right angles to what according to this conclusion is the main direction of vibration of the ether particles is commonly called the plane of polarization of the ray,—thus, in the case above supposed, of light polarized by a uniaxal crystal, the plane of polarization of the ordinary ray, *i.e.*, of the ray whose vibrations are at right angles to the crystal axis, is the plane in the direction of propagation which contains this axis.

That the two modified wave groups produced by polarization have different indices of refraction is evidently accounted for by the different velocity of ether particles moving in the two different directions of vibration.

The experiment with the two tourmalines above described shows that when the plane of polarization of a polarized ray which falls vertically upon a slice of uniaxal crystal cut parallel to the axis is not either at right angles to the axis of the crystal or containing this axis, two rays are produced, as in the case of the transmission of an ordinary ray through a double-refracting crystal, the only difference being that the two rays now have different intensity if the plane of polarization of the original ray is nearer to one direction of polarization in the crystal than to the other. We naturally attribute this separation of a polarized ray into two rays to some such separation of each ether fluctuation into two through the retardation of one portion of it compared with another as that we have just pictured in the case of polarization of ordinary light.

Polarization by Reflection.

It was discovered by Malus in 1808 that light reflected at an oblique angle from a glass surface is polarized, and

it has since been found that the transmitted light is also feebly polarized, the plane of polarization of the latter being at right angles to that of the former. It has also been found that other transparent reflecting surfaces besides glass exhibit the same effects.

When light is reflected from a plate of glass, or of some other transparent isotropic medium at a particular angle of incidence known as the polarizing angle,* which is such that the direction of the reflected light is perpendicular to the direction of that refracted, all the reflected light and a proportion equal to it of the transmitted light are found to be polarized, the plane of polarization† of the *reflected ray* being in all cases the plane of incidence and reflection.

And, finally, when a polarized ray is incident upon a plate of glass at the polarizing angle, and the plane of polarization of the ray is at right angles to the plane of incidence, no sensible reflection takes place, and the whole ray is transmitted.

To make the phenomenon of polarization by reflection and refraction more apparent it is usual to employ a pile of about a dozen glass plates, so as at once to increase the amount of light reflected and strengthen the polarization of the light transmitted.

We will now endeavour to show that the same theory of polarization as that above suggested in the case of polarization by crystals is applicable to the case of polarization by reflection.

We concluded in a previous chapter that when light falls obliquely on a surface between two different transparent media the proportions of any given fluctuation transmitted and reflected respectively will not be the same in all parts of it, but will vary according to the

* This angle for glass is generally about $56^{\circ} 35'$.

† See p. 279.

direction of radiation of the ether particles, and that this is so whether the direction of incidence is towards, or from the more-refracting of the two media (pp. 227 and 228).

Now, since in any group of waves all transverse dimensions measured in the direction of the plane of incidence *after* refraction bear to corresponding dimensions measured *before* refraction the ratio of the cosine of the angle of refraction to the cosine of the angle of incidence (see p. 218), it appears evident—

(1). That, if, in the case of light passing *towards the more-refracting* of the two media, the angle of incidence is *great* enough to give the ratio just mentioned as great as the ratio of the velocities before and after refraction, the sudden increase, when refraction occurs, of the time allotted to *the portions of each fluctuation moving in the direction of the plane of incidence before they encounter neighbouring fluctuations* (p. 203) will compensate for the diminished capacity of transmission caused by the change of velocity, and these portions will pass unchecked through the surface between the media and will consequently contribute nothing to waves reflected from this surface.

(2). That, if, in the case of light passing *from the more-refracting* of the two media, the angle of incidence is *small* enough to give the ratio just mentioned as great as the ratio of the velocities before and after refraction, the sudden diminution when refraction occurs of the time allotted to *the portions of each fluctuation moving in the direction of the plane of incidence before they encounter neighbouring fluctuations* will not more than neutralize the increased capacity for transmission caused by the change of velocity, so that, as in (1), these portions will pass unchecked through the surface between the media, and will contribute nothing to waves reflected from this surface.

And, combining these conclusions, we reach the remarkable conclusion. That if a group of waves is incident upon a stratum of more-refracting medium *with parallel plane faces* at the particular angle which gives the ratio of the cosine of the angle of refraction at the first surface to the cosine of the angle of incidence that of the velocities in the less-refracting and more-refracting medium respectively, *the portions of each ether fluctuation moving in the direction of the plane of incidence will pass unchecked through both surfaces, and will consequently contribute nothing either to the waves*

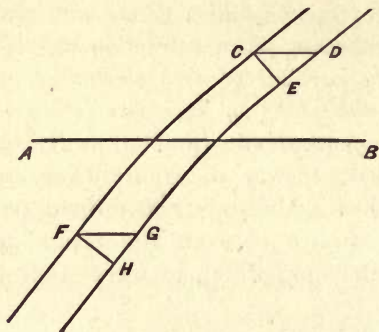


Fig. 32.

reflected externally at the first, or to those reflected internally at the second surface.

We shall now prove that this angle is that known as the polarizing angle.

Let the accompanying diagram be a section, taken in the plane of incidence, of two adjacent prism-shaped surfaces of maximum ether condensation before and after refraction at a plane surface AB between two media, and let their inclination to the surface be such that the cosine of the angle of refraction bears to the cosine of the angle of incidence the same ratio which the velocity of the

incident waves bears to that of the refracted waves, as in the case just supposed.

At some point c in the straight portion of the section of one of the prism-shaped surfaces in one medium draw CD parallel to AB , and CE perpendicular to this portion, and at some point F in the straight portion of the same section in the other medium draw FG parallel to AB , and FH perpendicular to this latter portion.

Then since $\frac{FH}{FG}$ = the cosine of the angle of refraction,

and $\frac{CE}{CD}$ = the cosine of the angle of incidence,

and $FG = CD$ (see p. 212),

$\frac{\text{Cosine of the angle of refraction}}{\text{Cosine of the angle of incidence}}$ (which by construction = ratio of the velocities) = $\frac{FH}{CE}$.

Again, since the ratio of the velocity in the incident waves to the velocity in the refracted waves is that of the sine of the angle of incidence to the sine of the angle of refraction,

and $\frac{DE}{CD}$ = sine of the angle of incidence,

and $\frac{GH}{FG}$ = sine of the angle of refraction,

it follows that $\frac{\text{cosine of the angle of refraction}}{\text{cosine of the angle of incidence}}$ also = $\frac{DE}{GH}$:

And therefore $\frac{FH}{CE} = \frac{DE}{GH}$ and $CE \cdot DE = FH \cdot GH$.

Therefore the triangles CDE , GFH are equal ;

And since $CD = FG$, they are also identical.

And therefore $DE = FH$ and $CE = GH$.

Therefore, finally, $\frac{DE}{CD} = \frac{FH}{FG}$, or the sine of the angle of incidence = the cosine of the angle of refraction—that is, the angle of incidence is complementary of the angle of refraction.

The natural conclusion from these facts seems to be that polarization produced by reflection at the polarizing angle is due to the reflection of such of the ether particles in the incident waves as vibrate at right angles to the plane of incidence being *greatest*, that of those vibrating parallel to this plane *nil*, and to a complementary state of things as to transmission.

As in the former case of polarization, it is difficult to trace precisely the nature of the modified waves produced, but, since opposite portions of each fluctuation would be withdrawn or separated by the causes just explained, just as they were by the difference in rank arising from the peculiar nature of the medium in the case of polarization by uniaxal crystals, it is a natural conclusion that the modified waves which result are similar in the two cases.

It is probable, however, that very considerable varieties of waves in some cases produce similar effects optically, and are indistinguishable from one another. Thus in the case of refraction at a single surface, the fact of the distance between the prism-axes after refraction being greater or less in one direction than in a direction at right angles to it seems to point to a breaking up of each fluctuation in the transmitted waves very similar to that which has been argued to be the cause of polarization in the case of a uniaxal crystal, and, notwithstanding this, the different portions having in this case the same index of refraction, the polarization, if any, *arising from this cause* is unrecognizable.

The fact above referred to that no sensible reflection takes place of a polarized ray incident at the polarizing angle and whose plane of polarization is at right angles to the plane of incidence, is evidently in harmony with the above theory. For we have concluded that the vibrations in such a ray are in the direction of the plane of incidence, and we have argued that vibrations having this direction

will pass unchecked through both surfaces of the medium and will contribute nothing to the waves reflected (p. 282).

We may remark that our supposition that the colour produced by reflection from small particles is due to different degrees of transmission of the different waves of the spectrum (p. 255) is supported by the experimental fact that such reflection is accompanied by plane polarization, for we have just concluded that plane polarization by reflection is due to partial transmission.

Attention is called to another method of producing polarization in a communication of some observations upon the diffraction and polarization effects produced by passing light through a very narrow slit, made to the New York Academy of Sciences by Mr. A. Michelson in the year 1880. If a fine adjustable slit be narrowed down very greatly, the coloured diffraction fringes widen out until, when the width of the slit is reduced to less than one-fiftieth of a millimetre, the central space only is seen, and appears of a faint bluish tint. Moreover the light so transmitted exhibits traces of polarization when regarded through a Nicol prism. If the slit is still further narrowed, the depth of the tint and the amount of polarization increase, until, when a width of only one thousandth of a millimetre is reached, the colour becomes a deep violet and is perfectly polarized. In this experiment the Nicol prism may be used either as polarizer or as analyzer. The polarization is in a plane at right angles to the length of the slit.*

These results have some additional interest in view of our conclusion that diffraction is due to refraction.

* Taken from *Nature*, No. 554, p. 133

CHAPTER XXV.

DEPOLARIZATION—COLOURS OF POLARIZATION—ROTATION
OF PLANE OF POLARIZATION, ETC.

IF we take two plates of uniaxal crystal each possessed of the property of transmitting one only of the two polarized rays into which it converts a ray of ordinary light,* and we place them so that no light passes (p. 271), and then we insert a third plate of uniaxal crystal between them, it is found that, unless the axis of the third plate lies in one of the two planes of polarization of the other two, commonly called “planes of reference,” light passes.

This effect, which is known as *depolarization*, is really the same to which attention has already been called, obtained by using two tourmalines (p. 271). For the first and second crystals of the series, and also the second and third, have the relative situations which allowed the passage of light in the case referred to ; and we saw that light traversing a uniaxal crystal is polarized in the same directions whether it was or was not polarized light before it entered the crystal, the only difference being in the relative intensity of the two polarized rays (p. 279).

* We have remarked that tourmalines, unless very thin indeed, fulfil this requirement, but, to display the phenomena we are about to consider, the instrument called a *Nicol prism* is usually employed instead of a simple plate of crystal. This instrument consists simply of two pieces of Iceland spar, cemented together by Canada balsam, and shaped and adjusted in such a manner as to totally reflect, at the surface of union, one of the polarized rays, and thus get rid of it.

There are, however, some remarkable colour effects, produced when the plate of crystal thus interposed is very thin, which demand explanation.

Thus, if a slice of selenite of about the thickness of paper be introduced between two Nicol prisms with its plane perpendicular to the course of a ray of white light which is traversing them, and the Nicol prisms are crossed in the way described, the light of depolarization is coloured. And further, while the Nicols are thus crossed—

1. Rotation of the selenite only, keeping it in the same plane, merely alters the depth of the colour and does not change its tint. When the direction of the axis of the selenite bisects the angle between the two planes of reference the colour is deepest. When it lies in either of these planes light is abolished; there is no depolarization.

2. Different thicknesses of selenite produce different tints; any particular tint, however, being produced by each of a certain series of different thicknesses. A plate ground concave, consequently, gives an arrangement of colours exactly like that produced by a film of graduated thickness, and known as "Newton's rings" (p. 246).

3. When a plate of selenite is too thick to produce colour if interposed alone, it may be made to do so by introducing another plate of almost equal thickness with its axis at right angles to the axis of the first plate; so laid the plates are said to be crossed. When the thickness of the two plates is the same there is no colour.

A change in the relative position of the Nicols such that their planes of polarization are coincident instead of crossed, is found, when white light is employed, to substitute complementary colours when we use the same selenite. When instead of white light we use monochromatic light, such a change substitutes darkness for light, light for darkness.

Finally, there is for each particular wave-length a certain series of thicknesses for selenites which give uniform in-

tensity of the transmitted light *during rotation of the second Nicol*, the axis of the selenite and the axis of the first Nicol remaining stationary at a constant angle of 45° to each other.

The explanation of these phenomena which we have to submit is as follows :—

We have concluded (p. 279) that the separation of a polarized ray into two rays when it traverses a uniaxal crystal, is due to some such separation of each ether fluctuation into two, through the retardation of one portion of it compared with the rest, as that we have argued to

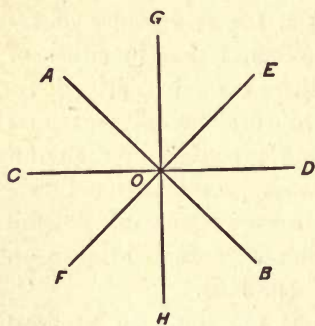


Fig. 33.

occur in the case of polarization of ordinary light. Suppose that the plane of the accompanying diagram (fig. 33) represents that of the surface of a uniaxal crystal cut parallel to its axis, and that the crystal is held perpendicular to the course of a monochromatic polarized ray ; and let A B be the direction of the plane

of polarization of this ray, and C D the direction of the crystal axis, making an angle of 45° with A B.

Then, if the crystal used be thick enough to effect complete polarization in the two new directions proper to it, we must picture one series of modified waves in the crystal suffering a change of the plane of principal radiation of their ether particles from the direction E F, perpendicular to A B, to the direction C D, and the other series, whose velocity will be different, suffering a similar change of the plane of principal radiation of their particles from the same direction E F to the direction G H, perpendicular to C D ; and, as each wave-fluctuation which occurs while this

change is taking place has an onward movement in the direction of propagation, we conclude that *during the progress* of the above changes both series of modified waves have some sort of screw-spiral motion, the axes of the spirals followed lying in the direction of propagation.

Again, since we must suppose that the unequal resistance of the medium of crystal exerts the deflecting influence on the direction of vibration of the waves *so long as they do not vibrate chiefly in one or other of the directions* CD , GH , we conclude that the impetus acquired by a wave fluctuation *in a spiral direction oblique* to the direction of propagation will cause the change of direction of the plane of principal vibration to continue after its ultimate direction CD , or GH , as the case may be, has been reached, so that the plane of principal vibration will at this juncture pass out of the quadrant DOG , beyond DO in the case of one series of modified waves, beyond GO in the case of the other; and further that, as the deflecting influence of the crystal will then act in the opposite direction, a reverse change will follow in each case, which will cause the plane of principal vibration when it has moved a little into the quadrant DOH , or into the quadrant $GO C$, to return towards its ultimate direction CD , or GH , and again to repass this direction, and so on, oscillating from side to side of it;* and we conceive that the *locus* of the change of direction of vibration of the waves thus described will cut the direction of propagation at a smaller angle at each oscillation.

Finally, as the oscillations described start in opposite directions, it is evident that, for a time at least after entering the crystal, the planes of principal vibration of the two series of modified waves will, as the waves penetrate the crystal, alternately lie in the same, and in opposite quadrants; beginning to diverge in the same quadrant

* A rough comparison may be made to the oscillation of the compass needle occurring when a ship changes its course.

D O G or C O H, they will pass into opposite quadrants C O G, D O H, then back again into the same quadrant, and so on with a regular rhythm ;—

To apply these conclusions to the phenomena under consideration :—

When the crystal used is so thin that the ether waves pass out of it before the polarization in the new directions is completed it is evident, since the deflecting influence due to the nature of the crystal ceases at the point where the ether waves leave the crystal, that the nature of the transmitted waves will depend, on what *phase of oscillation* the planes of principal vibration have reached at this point, and therefore on the thickness of the crystal.

And, as a Nicol prism whose plane of polarization has the direction E F transmits only vibrations occurring in the quadrants C O G, D O H (see p. 286), the consequence of the oscillations of the planes of principal vibration alternately into and out of these quadrants will be that a gradual increase of thickness of crystal will give alternate light and darkness when the rays emerging from it are passed into such a Nicol ; a transition occurring at every increment of thickness which allows of an additional oscillation.

When the Nicol is rotated through 90° it is manifest we must look for complementary results.

We appear therefore to have a satisfactory explanation of the phenomena described.

The fact, that rotation of the selenite only does not change the tint of the colour produced, goes to indicate that a particular thickness of selenite produces the same number of oscillations whatever the direction of polarization of the rays with respect to its axis is when they enter it.

That the colour is deepest when the axis of the selenite makes angles of 45° with the planes of reference indicates that the proportion of moving ethers in each modified wave

taking part in the oscillations becomes smaller as its original plane of vibration lies nearer to the new direction proper to the selenite.

Circular Polarization.

If we accept the above explanation, it is evident that when the phase of oscillation reached in the case of waves of a particular wave-length is such that the plane of principal vibration in one set of modified waves is found at right angles to the plane of principal vibration in the other set, and the two sets have equal powers of producing light, the proportion of the light transmitted upon passage through a second Nicol will be equal to the portion repressed, in all positions of this Nicol ; and this conclusion is in harmony with the fact referred to, that there is a certain series of thicknesses for each wave-length which produce this constancy when the axis of the selenite makes angles of 45° with the planes of reference. The light transmitted in this case is distinguishable from common light by the effect upon it of the introduction of an additional plate of selenite.*

It has been found that when the peculiar ether waves thus obtained are transmitted through a plate of selenite of the same thickness as that which produced them they return to the condition of plane-polarization.

Fresnel has discovered that modification of plane-polarized light, similar in its effects to that we have been considering, is produced by *total internal reflection in glass* whenever the plane of polarization of the incident light is inclined to the plane of incidence, and following up this discovery he has succeeded in so modifying plane-polarized light by reflection in this way as to obtain the kind of

* It is usually called "circularly polarized" light from the supposed circular motion of its vibrations according to the undulatory theory of light.

waves above referred to which give the proportion of light transmitted the same in all positions of a Nicol.

The following was his method :—

He constructed a rhomb of glass having parallel faces whose angles and dimensions were such that a ray entering at one face vertically was totally reflected twice within the rhomb at an angle of $54^{\circ} 37'$, and passed out vertically to the face opposite the one at which it entered ; he then caused a polarized ray to pass through in this manner with its plane of polarization inclined at an angle of 45° to the reflecting surfaces, when the emergent light had the property desired.

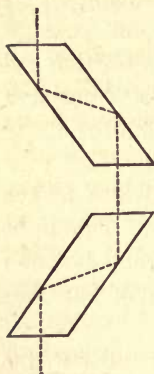


Fig. 34.

Fresnel found further that when a polarized ray was passed in this way through two such rhombs whose corresponding faces were parallel, its polarization was finally restored unchanged, but that if the second rhomb had a reverse position (see fig. 34) the ray became polarized in a plane at right angles to its first plane of polarization.

From the fact that polarized waves thus modified have the same properties as polarized waves modified by passage through a thin selenite it is natural to conclude that the modification is quite, or nearly identical in the two cases, and that reflection in the way described, unaccompanied by transmission, has the effect of separating each fluctuation in the plane-polarized waves into two, one of which falls behind the other.

It appears in harmony with this conclusion that, as just stated, "circularly polarized" waves produced by the passage of plane-polarized waves through a Fresnel's rhomb can by passage through a second rhomb be brought again to a state of plane-polarization, *either* in the original

plane, or in a plane at right angles to it, according to the position of the second rhomb. For a glance at our diagram (p. 288) seems to show that the change requisite to convert modified waves, such as we have supposed, which have two planes of principal vibration similar to each other in CD and GH (p. 288) into plane-polarized waves with their principal direction of vibration parallel to AB would be *precisely similar* to that requisite to convert such waves into plane-polarized waves with their principal direction of vibration parallel to EF .

A Fresnel's rhomb produces "circular polarization" of all wave-lengths equally.

Rotation of the plane of polarization by some media.

If a thick plate of quartz cut perpendicularly to the optic axis be placed between two Nicols through which a beam of parallel plane polarized light is passing, colour is produced; and the cause of this has been found to be a power possessed by quartz of slightly rotating the planes of polarization of rays traversing it; the amount of rotation produced being different for different wave-lengths; the nearer the place of a group of waves to the violet end of the spectrum, the greater the rotation. Some crystals produce the rotation in one direction, others in the opposite, one kind being distinguished as *right-handed*, the other as *left-handed* quartz. The angle through which rotation occurs in the case of any particular ray is always proportional to the thickness of the quartz plate.

As to the cause of the phenomenon, the consideration of the molecular structure of quartz crystals is appropriately deferred until we come to deal with the subject of crystallization; but we may say here that arguments will be then adduced to prove that the arrangement of small masses of different kinds of matter in this substance is such that, as we travel along any principal axis, the directions of greatest and least resistance to ether movement (p.

272) in plane elements of mass of small area lying perpendicular to this axis have relative situations resembling those of winding stairs, the spiral which they follow being right-handed in some crystals, left-handed in others. And the slight rotation of their planes of polarization experienced by polarized ether waves in traversing a plate of quartz is, it is suggested, the result of this peculiarity of structure.

Other substances displaying the same property—*e.g.*, a solution of sugar—probably have an arrangement of their particles in spiral forms somewhat analogous to the arrangement ascribed to quartz.

The numberless beautiful polarization effects obtained from various crystals may be explained in the same manner as the simpler phenomena we have considered.

Take for example the well-known phenomenon of coloured rings intersected by a colourless cross,—black, if the Nicols are crossed ; white, if they have their planes of polarization identical,—which is produced by using a plate of Iceland spar about one-eighth of an inch thick, cut transverse to the crystal axis, and employing convergent or divergent light.

Here all the polarized light from the first Nicol, except that passing perpendicular to the plate of crystal, and also except that whose oblique direction through the plate lies in one of the planes of reference, experiences double refraction, and the same arguments apply as in the case of a thin selenite (see p. 287), noting, however, that the direction of the rays being now but slightly inclined to the crystal axis, the difference of elasticity encountered by them in different transverse directions is but little ; and, consequently, that the angles at which the change of direction of vibration of waves in course of modification (p. 289) cut the direction of propagation are very small, and the distances in the crystal at which such oscillations as are above described recur, are proportionately greater.

When unannealed glass is placed between two Nicols, it gives beautiful indications of the existence of lines of greater resistance, and therefore less velocity, very similar to those apparent in crystals ; and other glass, which, like some regular crystals, is isotropic, passes from this condition when it is subjected to strain or pressure, and exhibits striking phenomena of polarization. Beautiful experiments illustrating this are well known, and are figured and described in the text books ; the explanation suggested of the last-mentioned fact is that the strain diminishes the elasticity in one direction, as compared with another, of the cell walls which we have argued are present in the cellular solid state (p. 28).

Magneto-optic Rotation.

The celebrated discovery made by Faraday, that the plane of polarization can be rotated by the action of magnetism, will next occupy our attention ; as since amplified, it may be broadly stated thus :—

If, around a transparent substance, fluid, solid, or gas, through which a ray of polarized light is transmitted, an ordinary electric current is travelling in a direction transverse to the direction of the ray ; or if, in place of such a current, a powerful simple magnetic force is in operation in the direction of, or against the direction of the ray, then the plane of polarization of the transmitted light is slightly rotated or deflected, the direction of the rotation being uniform with respect to the direction of the current when the same substance is used, and generally with, but, in the case of some few substances, against the direction of the current. Further, the amount of rotation is directly as the strength of the current, and directly as the length of the transparent medium traversed by the light under the given conditions. And finally, the law for the relative amounts of rotation of

different colours is approximately the same as in the case of quartz.

The following is the explanation of the phenomenon, which flows naturally from our conclusions that electricity and magnetism are alike results of the motion of unmo-
lecular ethers.

Like as the vibrations of the air which propagate *sound* are deflected by currents of air or wind, a fact familiar to all of us, we must suppose the incomparably more rapid vibrations of the subtle ethers which propagate light will be deflected by any swift current of these ethers whose

continuous flow in some particular direction is producing phenomena of electricity or magnetism.

To apply this to the case under consideration. In fig. 35, let a section at right angles to the course of a ray be represented, and let o be the centre of the space $xyx'y'$ surrounded by the circuit of the electric current, which

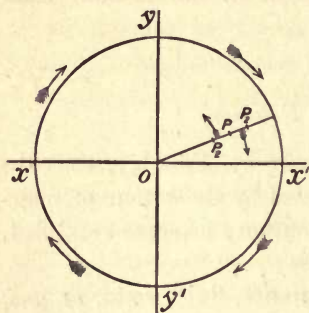


Fig. 35.

space is filled by some transparent substance ; and let $x o x'$ be a line drawn through the point o in the original plane of polarization of the ray. Then what we have to show is that the waves which pass through any point P within the space $xyx'y'$ will experience some rotation of their ethers about this point as the consequence of the passage of a current of ether round outside $xyx'y'$ in the direction indicated by the arrows.

It is evident that the cohesion subsisting between particle and particle of the unmo-
lecular ethers within and without the space $xyx'y'$ will cause any rapid movement of those without to be to some extent participated in by similar

ethers within this space, and consequently that the passage of an ether current in the direction supposed will cause rotation about the centre o of the unmixed ethers found within the circuit.

Again, it is manifest that, both on account of the inertia of the ethers which has to be overcome, and also because the circumferences which they have to traverse are less the nearer we pass towards the centre o , *the velocity of the ethers moving within $xyx'y'$ will rapidly diminish from the circumference towards the centre.*

If, therefore, in a radius drawn through P , two points, P_1, P_2 , be taken, one on either side of P as near as we please to it, we see that the difference between the velocity at P_1 and that at P_2 will constitute a *couple*, tending at any given instant to produce rotation about P in the same direction as that about o .

It follows that radiations of each ether from a prism-axis situated at P will experience some slight deflection or rotation *in the same direction as the current of this ether.*

It is evident that this theory accords with the fact that the direction of rotation is independent of the direction of the ray, and not as in the case of rotation produced by quartz; also that it exactly fits the facts named, that the amount of rotation is directly as the strength of the current, and also directly as the length of the transparent medium traversed by the light under the given conditions, and that the relative amounts of rotation of different colours depend on the wave-length, following the same order as in quartz rotation.

That the direction of rotation is in some cases that of the positive electricity of the surrounding current, in some cases that of the negative, we naturally account for by supposing that in some substances the ether waves of light are chiefly propagated through *positive* ether, in other substances chiefly through *negative* ether.

It has been observed with regard to gases that those gases which have the highest indices of refraction possess the greatest rotatory power upon a polarized ray, when subjected to magnetic influence.*

In closing our remarks on the subject of light, just a word may be said respecting the new instrument devised by Professor Bell, known as the *photophone*.

This instrument stands in much the same relation to the telephone as the heliograph does to the telegraph, an intermittent or vibratory beam of light being the carrying agent. To describe it,—We have first a transmitter, consisting of a plane silvered mirror of thin glass or mica. Against the back of this flexible mirror the sounds which it is desired to transmit are directed. Transmission is effected by means of a powerful beam of light caught by a lens from the sun and directed upon the mirror, which is so placed as to reflect the beam in the direction required. The beam is received by another mirror, and concentrated upon a simple disc of hard rubber fixed as a diaphragm across the end of a hearing tube; or other receivers may be used in which the variation in electrical resistance of selenium under varying illumination is the essential principle.†

The fact that the fluctuations of intensity of the transmitted beams of light, induced by the slight variations in angular direction of the points upon the reflecting surface, duly chronicle themselves in corresponding vibrations in the receiver, or, in the case of selenium, in changes of conductivity, is in harmony with our conclusions that light produces molecule destruction in the bodies upon which it falls; for, if fluctuations in the amount of molecule destruction produced at the receiver are occurring,

* *Nature*, No. 539, p. 408.

† *Nature*, No. 569, p. 481. Art. by Sylvanus P. Thompson.

corresponding to the fluctuations in the intensity of the light, it is a natural conclusion that these fluctuations are the immediate cause of changes of form of the receiving diaphragm which reproduce the vibrations of the transmitter.

A further reference to this subject will be made under the heading of Heat, the explanation of the phenomenon having been recently referred to the action of radiant heat.

HEAT.

CHAPTER XXVI.

DIFFERENT ASPECTS OF THE PHENOMENON OF HEAT —
HEAT AN AGENT WHICH PRODUCES CHANGE OF BULK OF
MOLECULAR MATTER—THERMOMETRY.

THE property or condition known as *Heat* has several different aspects, and consequently an investigation of its nature may be approached from different sides. Thus :

(1). Physiologically it is a condition revealed to us by a distinct sensation not confined to any one organ of our bodies, but producible in any part. And to this we may add that it is the ever-present companion in organic matter of all vital operations, and also of the abnormal conditions of disease and decay.

(2). It is the subtle irresistible expansive force of the universe, generally revealing itself by the increase of dimensions of bodies which it affects.

(3). It is a property which resembles light in the manner of its transference or extension from one point in space to another.

As our inquiry here is not as to the nature or causes of the sensation we call heat, but as to the condition of matter to which the name is applied, we shall defer consideration of the physiological aspect of heat to a future chapter, and therefore our choice of a conception to start with lies between (2) and (3). We naturally select (2), as

most in harmony with our view that expansion of the ethers is the source of all material force, and suggest the rudimentary definition that *heat is a condition of molecular bodies whose development causes them, while under a constant general pressure, to either increase or diminish in bulk*; most bodies, as mercury for example, increasing with an increase of heat. This definition is evidently in harmony with the principle of thermometers, which measure heat by the expansion of mercury or some other liquid.

We have concluded that at all points of every mass of matter the cohesion is kept fluctuating in value by passing waves of alternating compression and expansion, and that the transition from the liquid to the gaseous state is brought about by the lowering of the minima values of the cohesion, thus kept fluctuating, past a certain critical value (p. 33). In harmony with the latter conclusion we now suggest *that the expansion of bodies by heat is due to a lowering of the minima of the fluctuating values of the cohesion, and a consequent diminution of the restraint exercised by this cohesion on those of the atoms of the mass which are endeavouring to expand.*

This reference of mere change of bulk to a similar cause to that to which we have attributed change of state is evidently favoured by the fact that *both* changes are commonly due to heat. It receives more direct support from the fact that liquids with high boiling points expand less at the temperature 0° C. than do more volatile liquids.

The fact that bodies which dilate when heated do so with very great force harmonizes with the reference of change of bulk produced by change of temperature to the expansive force of the highly compressed ethers.

The lowering of the minima values of the fluctuating cohesion just supposed would, according to our arguments, cause increased molecule destruction in a mass in which it occurred, and we are thus furnished with an explanation of

the well-known facts that heat is commonly accompanied by light, electrical action, and chemical change ; for, in this treatise, all of these phenomena have been, or will be traced to the liberation of the ethers by molecule destruction.

To liberation of the ethers thus arising we shall argue that the transfer or extension of heat from place to place is always due ; the influence of the ethers liberated by molecule destruction on molecular matter being, we suppose, partly direct in cases where this matter is near the place of liberation of the ethers, partly indirect through the agency of ether waves which the exploding atoms of the destroyed molecules originate.

In the next place we suggest that, to a great extent, *the lowering of the minima of the fluctuating values of the cohesion*, to which we have just attributed the increase of bulk commonly produced by heat, *is due to an increase in the quantity of the unimolecular ethers present within the interstices of the mass affected, which causes these ethers, and the atoms at the molecular surfaces in contact with them, to experience a fall of density.*

The thermal functions thus attributed to the unimolecular ethers, as distinguished from their electrical functions, will, it is believed, be found very fully elucidated in the following pages ; we may, however, just remark here that while, on the one hand, the phenomena of electricity have been argued to be the outcome of the presence of *an excess of one kind of ether*, and therefore to be in all cases evidence of the presence of unmixed ethers, the electrical functions of the ethers ceasing directly they become symmetrically intermixed ; on the other hand *the thermal functions* of the unimolecular ethers will be argued to be exercised *more especially by symmetrically-intermixed ethers, i.e., by masses of unimolecular ethers in which one ether is neutralizing the other electrically.* This would account for thermal effects

being frequently more abiding and manifest than electrical effects.

As in harmony with a reference of change of volume produced by heat to the influence of an increase in the quantity of unimolecular ethers present at the place where such a change occurs, we may refer to some experiments made by Professor F. Guthrie, F.R.S., which exhibit the variations in the electric conductivity of metals, produced by heating them. Thus he shows, by means of a gold-leaf electroscope, that a red-hot iron ball, when highly heated, will neither discharge the positive prime conductor of a glass electrical machine nor the negative one, but, on cooling the ball, a temperature is found at which the ball discharges the negative conductor, but not the positive one. On cooling the ball still further (but not below a glowing temperature) it is found to discharge both positive and negative electricity.* It is found that the rate of decrease of electric conductivity as temperature increases is nearly the same for most pure metals.

The above theory of the cause of changes of volume produced by heat is also in harmony with the fact that the subjection of molecular matter to various temperatures produces molecular changes which cause variation of its expansibility by heat analogous to the variation in phosphorescing power of glass when exposed to various different electrical conditions in a vacuum (p. 262). Thus thermometers are liable to an alteration of their zero points, it being found that if a thermometer is examined some time after graduation the melting point of ice is no longer at 0° C. but stands at some point rather higher, ranging between 0° C. and 1° . Further, a temporary change is produced in a thermometer by heating, and then

* *Nature*, No. 646, p. 475.—For some explanation of the phenomenon, see p. 318.

suddenly cooling it. Thus if a thermometer be placed in melting ice, and the freezing point noted, then plunged into boiling water, and after this replaced in the melting ice, it is found that the second registration of the freezing point is slightly lower in the scale than the former reading ; the original reading is recovered however after the lapse of from ten days to a fortnight.* This effect is evidently due to a change of bulk of the mercury, or of the glass tube containing it, or maybe of both.

The analogous fluctuations of the molecular condition of phosphorescence we have attributed to the action of temporary currents of the *unmixed* ethers ; the fluctuations of molecular condition revealed by the different degrees of expansibility by heat, above described, we regard as effects of the temporary application of increased quantities of the *intermixed* unmolecular ethers.

It has been observed of certain crystalline bodies, as idocrase and garnet, that a temporary diminution of density is produced by the application of a red heat.

It is important to notice that while molecular expansion is produced in most bodies by an accession of heat, or rise of temperature, in some bodies the same effect is produced by a fall of temperature. The question of the relative claims of *heat and cold* to recognition as positive agents, which thus arises, will receive some consideration presently ; it is evidently not a question which affects the validity of the conclusion that two different temperatures of the same body are two different ether states prevalent among its atoms.

Before proceeding to explain various phenomena of heat upon the basis of the views as to its nature thus presented we will say a few words as to the method of accurately determining differences of temperature.

* Compare with Note †, p. 262.

Thermometry.

It has been already noticed that an access of heat in the case of most bodies produces an increase of bulk. For instance a bladder not quite full of air, and having its orifice closed, will soon be quite full if it is heated, the same quantity of air occupying a larger space at a higher temperature, though remaining subject to the same atmospheric pressure. Now, if we compare different bodies, it is found that the same additions of heat to bodies of different kinds do not produce increases of bulk in precisely similar proportions in all cases. Thus, suppose the increase of bulk of two different bodies produced by a certain access of heat is noted, and suppose after this heat has been withdrawn, or dissipated, sufficient heat is applied to expand one of the bodies to a bulk which is an arithmetic mean between its bulk at the normal temperature and its increased bulk which has been noted, then it is generally found that the bulk of the other body at the same intermediate temperature is not precisely an arithmetic mean between its normal bulk and its increased bulk which was first noted. It is, however, found that the heat expansion of most bodies approximates very closely to this regularity of increase, and this is the case more particularly when gases in a state of great tenuity are compared. In consequence of this close approximation to regularity in the heat expansion of different bodies, thermometers filled with different fluids may be made to register practically alike, *i.e.*, to register the same numbers of degrees of evenly divided scales at the same temperatures. If equal bulks of different gases, taken at the same normal temperature, are subjected to the same increase of temperature it is found that, very approximately, they experience the same increase of bulk; this is especially true of highly tenuous gases.

This fact, together with the fact just previously referred

to, forms the basis of what is commonly known as the law of Charles :—That the bulk of a volume of gas under a constant pressure is in the ratio of the absolute temperature ; a law which indeed conveys no more than is above stated in other words ; since a scale of absolute temperature is merely a record of the proportionate changes of bulk experienced by matter, more particularly by gaseous matter, at various temperatures.

The division of the scale of a thermometer into degrees of equal magnitude evidently defines that the expansion undergone by the body selected as a measure of temperature upon increasing 1° in temperature shall be constant, whatever the temperature at which the observation is made. This accords with the conclusion of Gay Lussac that the augmentation of volume which a gas receives when the temperature increases 1° is a certain fixed proportion of its initial volume at 0° C. ; and it does not accord with the conclusion of Dalton, that a gas at any temperature increases in volume, for a rise of 1° , by a constant fraction of its volume at that temperature. The existence of such a law as the latter would, indeed, involve that a series of increments of heat so selected as to produce a succession of *equal* increments of expansion of one body, or set of bodies (this being the principle upon which a thermometer is based), should produce a series of increments of expansion, not equal but in an ascending scale of magnitude (a geometric series), in another set of bodies ; evidently a most unlikely relation to be found subsisting, and indeed a relation inconsistent with hypothesis, if the expansion of gases is to determine the standard thermometric scale.

It is unnecessary for us to dwell on the various refinements to which recourse has been had to perfect instruments for measuring absolute temperature, or for ascertaining differences of temperature ; but we may say that evidence will be given presently that, if we estimate quantity of

heat by the scale of absolute temperature which has been referred to, quantity of heat varies as the quantity of intermixed ethers which produce it.*

We need not remind the reader that when a body has been selected for the construction of a thermometer, the calibration of the scale is arbitrary, and that, in fact, several different scales are in use, each of which, in order the more easily to insure uniformity in making observations with different instruments, is determined according to the position of certain definite, readily-ascertainable temperatures. Some reference will be made to the constancy of these critical points of temperature, such as freezing point, boiling point, etc., presently.

* See p. 320.

CHAPTER XXVII.

THEORY OF HEAT RADIATION.

WE will now endeavour to show that the experimental facts regarding production of heat expansion, and the transference of heat from place to place, are consistent with the above theory that the proximate cause of heat expansion is an increase in the quantity of the unmolecular ethers present within the interstices of molecular masses.

And, naturally, our first thought is of that wondrous luminary which is the great agent in producing both light and heat upon our globe. What, we ask, is the nature of that power which, continually emanating from the sun, crosses the amazing intervening spaces, and is felt and experienced by us as heat?

And first we remind the reader that a large body of evidence has established that heat is propagated in the same way as light. Thus :—

The radiation of heat through vacua proceeds with the same facility as the radiation of light.

The reflection of non-luminous heat rays follows the same law of reflection as rays of light, a fact proved by the ignition of phosphorus by non-luminous heat rays when it is placed at the focus of a concave metallic reflector on which the rays are falling.

The relative reflecting powers of different substances are, as nearly as possible, in the same order for heat as for light.

Non-luminous heat rays obey the laws of refraction ; Nobili and Melloni having succeeded, with the aid of a thermopile, in showing the position of the focus of such rays converged by a lens of rock-salt.*

And lastly, the remarkable properties of polarization, including plane-polarization, "circular" polarization, and depolarization, have been shown to belong to non-luminous heat rays, Professor Forbes having proved that when these rays are passed through two plates of tourmaline a marked diminution of heat occurs when the plates are crossed, and having also proved that such rays are polarized in the processes of reflection and refraction.

From this we conclude therefore that ether-waves of the nature previously described (p. 200) are the agents employed in transmitting the sun's thermal influence.

Next as to the way in which the ether waves produce heat in molecular masses upon which they fall, we have already concluded from the phenomena of absorption of light, and of fluorescence, that these waves produce atom explosion within bodies exposed to their influence ; *and it is to this internal atom explosion that we attribute the liberation of unmoolecular ethers productive of heat expansion.*

Supporting this view we may mention the following facts :—

Rock-salt, which permits most heat rays to pass through it, does not itself become perceptibly heated by the pass-

* Rock-salt, and ebonite, which latter substance is, as we know, perfectly opaque to light, are almost the only substances which are transparent to non-luminous heat rays, or, as it has been called, *diathermanous*.

A very pretty instance of the transparency of a body to heat and not to light is furnished by one of Tyndall's experiments, in which he cuts off the light-rays by the interposition of a cell containing a solution of iodine in bisulphide of carbon, and shows that such a cell is transparent to the dark heat rays by producing combustion at the focus of the rays beyond the cell.

age of light ; in other words there being very little absorption there is also no appreciable heating effect, a state of things evidently in harmony with the theories that absorption and heat arise from the same cause—internal atom explosion.

The same substance, rock-salt, radiates very little heat, only about 15 per cent. of the total lamp-black radiation for the same temperature.

Again, as an instance of the great heating effect on molecular matter of solar rays, which have not been sifted by passing through the denser portion of the atmosphere so as to “absorb” a large proportion of the heating rays:—A party of scientists from Alleghany Observatory, ascending a high mountain in the Western Territories (Mount Whitney), found that while near the summit among the snow-fields the temperature in a copper vessel, over which were laid two sheets of plain window glass, rose above the boiling point, and the faces and hands of the members of the party were more burned in the cold of the mountain summit than they had previously been in the hot desert which had been traversed to make the ascent.

Finally, as a closing reference in support of the above theory, we may mention that Tyndall and others have shown that the ether waves chiefly concerned in producing the sound phenomena of the instrument known as the photophone, a theory of which we have already offered, are the waves which belong to the red and ultra-red end of the spectrum, and that the molecular motions in the receiver which set up the sounds are rather those of confined gases, or vapours, than of vibrating discs. And Tyndall has further shown that sonorous effects may be produced by the intermittent illumination of all gases and vapours *which “absorb” radiant heat* and that the intensity of the sounds produced is a measure of the amount of absorption.*

* Proceedings Royal Society, January 3rd, 1881.

Thus the molecule destruction and consequent ether liberation produced by ether waves, to which we have ascribed the sounds produced,* must be considered effects of radiant heat.

Next as to the important fact that the heat-producing power of waves of different refrangibility is different.

When dealing with light, we referred to the well-known fact that when the ether waves of various wave-lengths, continually passing out from the sun, or from some other incandescent body, are assorted in a *pure* spectrum, they present a continuous series arranged in the order of refrangibility, those falling between certain limits of refrangibility being waves of light and composing the visible spectrum, and those outside these limits, at both ends of the spectrum, being waves of a similar nature to the luminous waves, but with wave-lengths either too great or too small to excite the sensation of light.

Now Melloni and others have, with the aid of a thermo-electric pile, ascertained that the following remarkable distribution of heat prevails in the complete spectrum :—In a tract comprising the dark rays beyond the violet, and the luminous rays for some distance from the violet end of the spectrum, no sensible heat is found ; in a succeeding tract, extending from the blue to a considerable distance beyond the red into the dark ultra-red portion of the spectrum, the heating power of the waves rises from zero to a maximum, the rise being at first very slow, but growing in rapidity till it becomes very steep in the ultra-red ; and, finally, in the remaining portion of the ultra-red, the heating power falls continuously from the maximum to zero again, the fall being at first very rapid, but having a gentler and gentler gradient as we pass towards the ultra-red limit, till it becomes very gradual indeed before it disappears.

The explanation suggested is, that while all the waves, of

* See p. 298.

whatever wave-length, produce atom explosion in a composite molecular body, such as the thermo-electric pile, the proportion of the different kinds of atoms exploded by particular waves depends on their wave-length, waves of great wave-length, *i.e.*, those whose place is towards the red end of the spectrum, destroying a larger proportion of such of the atoms as produce by their explosion waves of great wave-length ; and waves of small wave-length, whose place is towards the violet end, a larger proportion of such of the atoms as produce waves of small wave-length.*

Further, that waves whose place is towards the red end of the spectrum owe their existence chiefly to explosions of atoms composed of negative ether, while those whose place is towards the violet end owe theirs chiefly to the explosion of atoms composed of positive ether.†

Consequently, that the nearer the place of any particular waves is to the extreme beyond the red, the greater the proportion of negative atoms they destroy, and the quantity of negative ether they liberate ; and on the other hand, the nearer their place to the extreme beyond the violet, the greater the proportion of positive atoms they destroy, and positive ether they liberate.

Finally, that since, according to the theories of electricity previously offered, any excess of either ether when liberated passes immediately away by electrical conduction, the *more nearly equal* the quantities of positive and negative ether liberated by waves of any particular wave-length when they fall on molecular matter are, the greater will be the accumulation of intermixed unimolecular ethers they produce, and the greater the heat ; the waves which produce

* See Note *, p. 267, in favour of this.

† It is probable that the *luminous* waves can be propagated by either ether, and this is in harmony with the explanation we have given of the two opposite directions of magneto-optic rotation (p. 296).

maximum heating effect being thus the waves which liberate positive and negative ether in equal quantities.

According to these views, there are two factors which, by determining the nature of the atom explosion and consequent ether liberation occurring in a body when it is exposed to the action of ether waves, determine the heat produced.

1. The relative proportions of the different kinds of primary atoms which compose the body and are exposed to destruction by the ether waves.

2. The wave-lengths of the ether waves.

The first of these determines to what extent a body is diathermanous. Thus we have already suggested that the reason rock-salt is very diathermanous is that ether waves belonging to the ultra-red portion of the spectrum produce but little atom explosion within it, this being indicated by the fact of its experiencing but little rise of temperature when exposed to radiant heat.

The very great equalization of temperature which is found to result from the production of similar conditions at different places through the passage of ether waves between them has led to the general acceptance of what is known as *the theory of exchanges*, a theory according to which all bodies, at whatever temperature, are constantly radiating heat to one another; those of a constant temperature getting back as much as they give. It is interesting to notice that the theory of heat which has been offered justifies, to some extent, some such theory; for wherever there is heat we must look for atom explosion, and the origination of ether waves, and it is evident that if at two different points the ether conditions are similar, so that the amount of wave movement set up is the same at both, each point will experience a similar influence from the waves set up at the other; while, on the other hand, if the ether conditions are different at the two points, there will be a greater effect

at the point where there is less atom explosion due to the atom explosion at the point where there is more, than is produced at the latter point by the atom explosion at the former, where there is less.

The following experiment made by Pictet is generally supposed capable of explanation by the theory of exchanges ; but it seems probable that this theory, as just interpreted, is not adequate to the case :—

If ice, or a freezing mixture, is placed at the focus of a concave reflector, and a thermometer is placed at the focus of a second similar reflector, so arranged opposite to the first that rays, either light or dark, emanating from the focus of one are after two reflections brought together again at the focus of the other ; then the presence of the cold body is found to cause a fall of the thermometer.

The explanation, according to the theory of exchanges just suggested, would be, that, owing to the substitution at one focus of the cold body in place of the air at normal temperature previously present, there is a discontinuance of certain wave movements which were before being continually set up by atom explosions occurring in this air, and which were afterwards concentrated at the second focus, and that in consequence of this discontinuance there is a falling off in the amount of atom explosion and consequent heat-production at this latter focus.

This explanation does not appear adequate, and it is submitted that a more likely explanation is as follows :—

That in the cold body introduced there is a somewhat large amount of explosion of *atoms composed of positive ether* going on ; that this atom explosion sets up waves belonging to the ultra-violet portion of the spectrum ; that these waves being concentrated on the thermometer produce in its substance explosions of atoms composed of positive ether, and finally that the occurrence of these explosions prevents a good deal of explosion of atoms com-

posed of negative ether which would otherwise occur,* and thus causes a reduction in the supply of intermixed ether to whose presence heat is due.†

We thus suppose a radiation of cold to be possible as well as a radiation of heat.

The cooling effect caused by the near proximity of certain bodies, especially gases, arises, it is suggested, from a radiation of cold such as just described ; atom explosion probably occurring within the cooling body which sets up ultra-violet waves.

As an instance of the effect of which this explanation is offered :—If a wire which is glowing in air is suddenly immersed in a jar of hydrogen or coal gas, the heat is very much reduced, and, consequently, the brightness, which indeed almost entirely passes away.

The coolness found in proximity to large bodies of water is probably another instance.

This concludes our remarks on the radiation of heat.

* We have already argued that the explosion of some atoms commonly prevents the explosion of others. It is probable the effect of light in lowering combustion, a familiar example of which is the sun's light interfering with the burning of the fires in our grates, is due to the same cause explained in the text.

† The continual flow into space of the intermixed ethers will be referred to presently.

CHAPTER XXVIII.

CONDUCTION—HEAT PRODUCED BY ELECTRICITY—HEAT
PRODUCED BY FRICTION.

THE next producing cause of change of temperature at any point, that we will consider, is the spread to the point of a thermal condition subsisting at other points immediately around it—an effect known as *conduction*.

Of this we have an example if we stir together a mass of mercury which is at one temperature with a mass of water which is at another temperature, the masses of both substances being then brought to a common temperature lying between the two original temperatures of the bodies thus brought into intimate contact.

As another example, in which we have a better clue to the nature of the process :—If we take a uniform bar of solid metal, *i.e.*, of a body whose particles have a constant relative position, and heat the bar at one end by a source of heat which is at a constant temperature, we find that, while every point of the bar comes to stand at a constant temperature, there is a gradient of temperature in the bar, the temperature being lower and lower the further we pass from the heated end.

The theory we have to offer, which, like the theory of radiant heat just propounded, is based on the supposition that heat is due to an increase in the quantity of unimolecular ethers present, is as follows :—

That conduction is the result of the passage of portions of the unimolecular ethers from a point where a higher

temperature prevails to a point where a lower temperature prevails, the ethers not, however, passing by immediate electrical conduction, because they are intermixed and neutralizing each other electrically, but gradually filtering through the interstices of the molecular matter; much as we have argued, the separate ethers, when their continuity is broken by the molecular motions of a non-conductor, filter through it.*

As to the gradient of temperature observed in the experiment last described, this must evidently be attributed to the escape of the unimolecular ethers from the bar into the air outside it, this action being facilitated by the particles of air when heated moving away and giving place to colder particles, an effect known as *convection*.†

The theory that conduction of temperature is due to movement of the intermixed ethers from points where temperature is higher to points where it is lower, is supported by the facts that metals are good conductors of heat as well as of electricity, and that the order of thermal conductivity of different metals is the same as that of their electrical conductivity.‡ For this is the natural result of the degree in which movements of both unmixed and intermixed ethers seeking to pass in any particular direction are checked being determined by the *same* property of the substance traversed, *i.e.*, by the power this particular substance possesses of breaking ether continuity by its molecular motions.

* See p. 81.

† Convection is the combined effect of conduction and gravitation, the motions of a gas or liquid which facilitate the intermixture of the unimolecular ethers with it being chiefly due to the particles of this gas or liquid continually undergoing re-arrangement owing to variations in their specific gravity caused by heat-expansion.

‡ The order of their electrical conductivity is, as we have said, taken to be the inverse order of their electrical resistance (see p. 151).

It is evident that the comparative slowness of the movement of the intermixed unimolecular ethers through a conductor would give time for a considerable amount of convection and conduction from its surface into the surrounding medium.

The weight of our arguments is further increased by the fact that the conductivity of metals for heat, like their conductivity for electricity,* generally diminishes as the temperature increases. A natural explanation applicable to both cases seems to be that the increased quantity of intermixed unimolecular ethers present when a body has a high temperature aids the breaking of ether continuity,† and consequently hinders the passage through the body of both unmixed and intermixed ethers.

The reason why the electric conductivity of electrolytes, follows an inverse law, increasing with increase of temperature, is probably found in the nature of the change of state these bodies are undergoing as their temperature changes ; for it is probable that an increase of heat carries them further from the crystalline state, in which, as we have seen, conductivity is very low, towards a more completely liquid state.

M. Christiansen, of Copenhagen, has shown that the thermal conductivity of air increases with the temperature.

One or two simple examples of the conduction of heat which favour our views by showing that it is facilitated, or hindered much in the same way as conduction of electricity is, may be here referred to.

If a handkerchief is wrapped tightly round a polished ball of metal, and then held in the flame of a candle, some time elapses before the handkerchief begins to burn, but if

* See p. 303.

† Possibly the cause of this is that increased atom explosion incident to the increase of temperature causes the intermolecular motions to be more violent.

a ball of wood be substituted for the ball of metal, the handkerchief takes fire almost immediately. The explanation, according to the above theory, will be that the intermixed unimolecular ethers to whose presence the heat which produces combustion is due, are to some considerable extent carried off by conduction when the metal ball is used, but not when the wooden ball is used.

The action of Sir Humphrey Davy's safety lamp depends on the withdrawal by conduction, through the metal composing a wire gauze, of heat which would otherwise produce combustion.

As another similar example of conduction rapidly lowering temperature, and thus preventing combustion, we may mention the fact that shot or pieces of lead may be melted in a cardboard tray over a lamp flame without burning the card.

This closes our remarks on conduction.

Heat due to Electricity.

Let us next apply our arguments to the case of a change of temperature produced by electricity.

Many familiar instances of this, such as the firing of buildings and the scorching of trees and the fusing of metals by lightning, occur to all of us.

The explanation, according to the foregoing theories, very evidently is that when the two ethers of an electric charge come together they intermix and check one another's conduction, and instantly accumulating, produce the phenomenon of heat.

Besides the *primâ facie* support of our theories thus afforded, we have the following very important piece of evidence connecting heat with the accumulation of intermixed ethers.

Joule has concluded from experiment that the amount of heat generated by a continuous current in a metal wire

in a given time varies directly as the product of the electrical resistance of the wire into the square of the strength of the current, so that, if proper units be chosen, $H = R C^2 t$; where H is the quantity of heat generated in time t , R the resistance of the wire, and C the strength of the current.

Now we have already shown,* that, if we neglect the quantity of ethers liberated by destruction of the molecules of the conductor, which ordinarily we may suppose to be very small, Q , the quantity of ethers intermixed in such a wire, is expressed by the very same formula as that ascertained by Joule to express the amount of heat—i.e., $Q = R C^2 t$.

And therefore, if proper units be taken, it follows that $H = Q$; that is, *the amount of heat generated by a current in a conductor is equal to the quantity of the ethers of the current that become intermixed.*

We will here offer some explanation of the reversible heating effects of currents, discovered by Peltier.

He found, as we have previously stated, that when an electric current passes over a junction of antimony with bismuth in the direction from the former to the latter there is a rise of temperature at the junction, and when the current passes in the opposite direction there is a fall.

The following appears to be a probable explanation. One of the two metals, the antimony, is liberating through atom destruction within it an excess of positive ether, the other, the bismuth, an excess of negative. When the positive ether of a current sets from the antimony towards the bismuth, intermixture of the excess of positive ether liberated by the antimony with the excess of negative ether liberated by the bismuth is facilitated, but when the current sets in the opposite direction, such intermixture is hindered or prevented, the ethers as they are liberated being dragged

* See p. 159.

further apart. The additional quantity of intermixed ethers produced at the junction in the one case produces rise of temperature ; the decreased quantity in the other case produces fall of temperature.

Sir William Thomson has produced effects of a similar kind with conductors of the same uniform substance, but having different parts at different temperatures. Thus he has discovered that in a copper conductor an electric current produces a decrease of temperature when it passes from a cold portion to a hot. On the other hand he has found that in an iron conductor a current produces an increase of temperature when it thus passes. Our conclusion that the proportion of the two ethers emitted by a substance is different at different temperatures evidently furnishes the link which enables us to apply a similar explanation to that given above.

In connection with our reference of heat to the presence of the unimolecular ethers it is interesting to notice that Prof. Andrea Naccari has concluded from his experiments with a Holtz induction machine that in every case the negative electrode is less heated than the positive.*

Heat due to Friction.

Lastly, let us apply our arguments to the case of change of temperature produced by the rubbing or knocking together of molecular masses.

Of the force of resistance which opposes the motion of the surface of one body upon the surface of another body with which it is in contact, and which is known as *friction*, we may probably distinguish two kinds. (a) Friction between smooth bodies attributable to the cohesion between the atoms and highly condensed unimolecular ethers of two different surfaces when brought together.† (b)

* See *Nature*, No. 642, p. 376.

† It is suggested that the reason why two smooth plane surfaces

Friction between rough bodies, resulting in abrasion, and due to projections upon the surface of one solid body falling between projections on the surface of the other body, so that for motion of one body on the other to occur particles have to be torn away from one or other of the bodies.

We may suggest as an instance of the first kind, the familiar schoolboy trick of rubbing a bright button on the clothes. The considerable heat produced by this, and kindred cases of friction, we naturally attribute partly, probably chiefly, to an accumulation at the rubbed surfaces of intermixed unimolecular ethers dragged from within the bodies undergoing friction, partly to the liberation of ethers through the explosion of some of the atoms of the rubbed surfaces. Davy's experiment of rubbing two pieces of ice violently together until both are nearly melted by the heat produced is another interesting example of this kind of friction.

A familiar instance of the second kind of friction is the rubbing of a skidded wheel on a road; the abrasion of particles is proved by sparks of burning iron flying from under the wheel. In this case we should attribute the heat almost entirely to the liberation of unimolecular ethers by atom explosion.

As to the incandescence of the particles flying off in the case just referred to, this is no doubt an example of the combustion of matter through its minute subdivision, of which many instances, such as the spon-when brought together do not ordinarily adhere so as to form a continuous mass, as the existence of the hypothetic force of cohesion would at first sight appear to involve, is that the vigorous motions of the surfaces caused by passing ether waves prevent the actual contact from being to any considerable extent simultaneous or extensive. In cases of substances uniting when brought together, we suppose that by some means the fluctuations of one surface are brought into harmony, or synchronism with those of the other.

taneous combustion of finely divided lead and other metals, are so well known. The explanation offered of the production of heat sufficient to cause combustion, as the result of fine subdivision, is that atom expansion and destruction, and consequent heating, are caused by a lowering of cohesion about the atoms of the metal which arises through the exposure of a large amount of its surface, as compared with bulk, to the influence of the lower ether density prevailing in the air. A theory of the nature of combustion is given hereafter.

The considerable heat developed during the hammering and rolling of metals, like the heat of the second kind of friction, will be attributed to the liberation of ethers by atom explosion.

We have thus dealt with four causes of heat, viz. :—

(1) The impact of ether waves on molecular matter, or radiation.

(2) The spread of the intermixed unimolecular ethers in molecular masses, or conduction.

3) Electricity.

(4) The rubbing or knocking together of molecular masses.

All these we have endeavoured to show can be accounted for with the aid of our fundamental hypotheses.

Chemical action, which, next to the sun, is probably the most fertile source of heat, we shall endeavour to prove in a subsequent chapter (p. 371) owes its heat effects to the combined action of some of the above causes,—notably to electricity.

CHAPTER XXIX.

THE EFFECT OF HEAT IN PRODUCING CHANGE OF STATE.

WE will next endeavour to show that our theory of heat explains the familiar fact that the changes of state experienced by molecular matter are commonly traceable to changes of temperature.

With reference to the liquefaction of solid bodies by heat. Our supposition that this change of state is due to an increase in the quantity of unimolecular ethers being liberated in small quantities within the body exhibiting the change, taken in conjunction with our theory that rise of temperature is due to an increase in the quantity of unimolecular ethers present within the interstices of bodies, evidently accounts for the fact of the change referred to being associated with a rise of temperature.*

Next as to change of temperature producing those changes of state which we have referred to the action of the various atoms composing a molecular mass on one another, viz., the change from the liquid to the cellular solid state, that from the liquid to the gaseous state, and the changes converse to these two.

We have already alluded to the familiar facts that when water is near the boiling point, or near the freezing point, a change of pressure has the same effect as a change of temperature; a diminution of pressure while the temperature remains constant, or a *rise* of temperature

* In this connection we may refer to the fact of the coefficient of expansion of liquids increasing with the temperature.

while the pressure remains constant, producing vaporization in the one case, a diminution of pressure while the temperature remains constant, or a *fall* of temperature while the pressure remains constant, producing solidification in the other case.

The connection thus indicated between pressure and temperature we explain as follows :—

We have already referred each of the changes just mentioned to a lowering of the minima values of the fluctuating cohesion of certain atoms past a particular critical value (p. 32), and we have explained the observed effect of diminished pressure in precipitating these changes of state, as arising from the effect of a lowering of general pressure in lowering the minima of the fluctuating values of the local pressures, and, consequently, of the cohesion.

In accordance with this, in the case of an increase of temperature producing a similar effect to diminution of pressure, when either brings water which is just below boiling to the boiling-point, we suppose that the increase in the quantity of unimolecular ethers present within the interstices of the molecular mass, to which the increased temperature is due, like the diminution of external pressure, acts by lowering the minima values of the fluctuating density, and therefore the minima values of the cohesion of the atoms whose expansion produces the transition to the gaseous state.

On the other hand, in the case of a diminution of temperature producing a similar effect to a diminution of pressure, when either brings water which is just below freezing to the freezing-point, we suggest that the diminution in the quantity of unimolecular ethers present, which is associated with fall of temperature, causes a falling-off in the amount of atom explosion taking place at the molecular surfaces within the body, and that in this

way the local pressures which are partly kept up by this atom explosion, are lightened, and the same effect produced as that caused by lightening the general pressure, viz., the expansion facilitated of the atoms by which the transition to the cellular solid state is brought about.

In harmony with our suggestion that transition to the cellular solid state, and expansion to the state of gas, are alike due to atom expansion, we have the significant fact that many bodies which in the solid state have optical properties indicating that they are in the cellular-solid state, pass from the liquid to the solid state *with a rise of temperature*.*

We have already remarked (p. 35) that where a transition from the gaseous state to the solid or the liquid state occurs through change of temperature, and not through the application of external pressure, we suppose that the expansion of ether liberated by molecule destruction furnishes pressure adequate to effect the requisite condensation.

The liberation of some of the contained air from water, and the increased violence of the effervescence of ordinary aerated waters, produced by a rise of temperature, are to be explained in the same way as the conversion of liquids to gases by heat.†

Some interesting facts have been ascertained as to the influence of the presence of small or large quantities of foreign bodies in changing the freezing and boiling points of a substance throughout which they are dispersed, or in near proximity to which they are placed.

Thus M. Donny has concluded that the boiling point of

* There are many organic substances that do this. As a very familiar example we may mention the solidification of the white of an egg, the act of solidification being accompanied by an increase of bulk often sufficient to break the shell.

† See Note *, p. 33.

water is as high as 135° when it is freed from atmospheric air by a process of long-continued boiling.

We have argued that the manner of effervescence of aerated waters affords evidence that wherever a particle of air contained in a liquid expands to the gaseous state a fall of the fluctuating pressures takes place (see note *, p. 33), and this conclusion affords a natural explanation of the power of contained air to facilitate ebullition.

Again, if water is deprived of the air which it ordinarily contains, and caused to cool very slowly and without agitation, it may be reduced to -6° C. before it congeals; and if it be enclosed in a tube, its surface covered with oil, and the atmospheric pressure removed, it may even be reduced to -12° . In this case, however, a slight agitation, or the presence of a piece of ice, sets up crystallization, and it is found that the whole at once rises to the temperature of water.

Capillary attraction appears to retard the formation of ice, Despretz having succeeded in lowering water contained in capillary tubes to -20° C. without congelation.

We have supposed that a fall below a critical point of the fluctuating local density and pressure when at a minimum causes a body to pass from the liquid to the cellular solid state, and probably such a fall may when a liquid approaches freezing point be brought about by any disturbance or irregularity in the arrangement of the atoms which brings together in an unsymmetrical manner atoms of different elasticity. As to the rise of temperature which takes place when crystallization commences, this belongs to the subject of latent heat and will be dealt with presently.

Finally Achard noticed in 1785 that the boiling point of water is much more inconstant in metallic than in glass vessels; also that the addition of a drachm of iron filings, or some other insoluble solid to water boiling in a glass

vessel lowers the boiling point. And, on the other hand, Magnus, Marcet and others have shown that the presence of the salts in saline solutions raises the boiling point in the scale of temperature.

Possibly the effect of metallic bodies, just referred to, is an electrical one, an excess of one ether present in those bodies (see p. 141) facilitating the atom expansion to which ebullition is due. As to the effect of the presence of salts we should be disposed to refer it to the salts taking the place of air which would otherwise facilitate ebullition as above explained.

The explanation of the constancy of temperature observed while a change of state of any molecular mass is proceeding belongs to the subject of latent heat, which will be dealt with immediately.

CHAPTER XXX.

CALORIMETRY.

Specific Heat.—Latent Heat.

WE will now pass on to consider some facts as to the capacity of different bodies to contain heat, which, in showing the subjection of heat to quantitative laws very similar to those which rule the behaviour of matter generally, afford strong evidence in favour of our theory that heat is produced by the presence of ethereal matter, *i.e.*, of the intermixed unimolecular ethers. These facts relate to what are called respectively the *specific heat* of substances and *latent heat*.

As a word of explanation of what specific heat is, we may say, that when equal weights of two bodies composed of different substances are subjected to the same increase of heat, for a certain limited period, it is found they do not experience the same rise of temperature. Thus the heat requisite to raise a kilogramme of water from 0° to 1° C. is found adequate to raise the same quantity of alcohol from 0° through a much greater range of temperature than 1° ; or, putting it in another way, it is adequate to raise a much larger quantity of alcohol than one kilogramme from 0° to 1° C. The ratio between the respective quantities of heat requisite to raise one kilogramme of water from 0° to 1° C., and to raise similarly one kilogramme of some other substance, is considered to be expressed by the inverse of the ratio between the quantity

of water and the quantity of such other substance raised from 0° to 1° C. by the same quantity of heat; and this ratio is called the specific heat of such substance in terms of the specific heat of water; or, shortly, its specific heat.

As to latent heat. It is found that when a body changes its state, a sudden fall or sudden rise of temperature takes place which is quite distinct from the change of temperature which is producing the change of state, *e.g.*, water at 0° C. in changing to ice at 0° disengages considerable heat. Heat which thus suddenly appears is spoken of as having been latent in the substance before the change of state, and on the other hand heat which suddenly disappears is said to become latent.

It is evident that, according to the theory of heat which has been offered, the temperature of a body is determined by the overflow, as it were, of the unimolecular ethers from within its interstices, or, in other words, by the quantity of intermixed ethers it gives off by conduction to another body (a thermometer for instance). Therefore to explain differences of specific heat we may suppose that in different substances the *storage capacity** for unimolecular ethers

* It is, perhaps, necessary to remark that in using the word *storage* it is not intended to convey that there is any condition of permanent equilibrium in which the mixed unimolecular ethers continue intermingled among the particles or minimum masses of a body, so as to form an *abiding* portion of it. On the contrary, we argue that, since stable equilibrium is not reached till a mass consists of *two* differently compressible kinds of minimum masses *only* (see pp. 9 and 355), the fluctuations of local density which every substance continually experiences will always tend to expel the unimolecular ethers from within it. The presence of the unimolecular ethers among the atoms of a body is therefore to be regarded as an essentially temporary condition, and the word *storage* is to be taken to express merely the temporary accommodation furnished to unimolecular ethers under the conditions subsisting in the field under observation.

A simple experiment of Tyndall's may be referred to as strikingly suggestive of specific heat being due to ether storage. Two pre-

increases and diminishes at different rates under given fluctuations in the amount of heat to which they are exposed.

And to explain the phenomena of latent heat we may further suppose that this storage capacity is different for different states of the same body.

Further, according to this mechanical view of specific heat and latent heat, we may suppose that the conditions which determine the storage capacity of a mass when the unimolecular ethers are by some means liberated by, or driven among, its atoms are two in number. (*a*) The amount of actual space becoming available within the mass at the time of observation for storage of the unimolecular ethers. (*b*) The density of these ethers, which, according to our previous arguments (p. 27), we expect to be regulated by the density of the mass.

Let us first apply these views to the case of specific heat.

The determination of the specific heats of bodies appears to be a difficult operation, and at best incapable of extreme exactness; some few approximate laws have, however, been ascertained.

Thus, as the result of the determination of specific heat, made by Regnault, we have two laws:—

(1). The specific heats of equal volumes of the simple and practically incondensable gases are approximately equal.

cisely similar prisms, one of bismuth, the other of iron, are placed upon the lid of a hot vessel, the tops of the prisms being previously coated with wax. It is then found that the wax upon the bismuth melts before that upon the iron, although iron is the better heat conductor of the two; the reason being that the specific heat of the iron is greater than that of the bismuth.

The fact that an insulated conductor does not retain a charge of heat in the same way as it retains a charge of electricity is perhaps due to the ethers when intermixed being capable of passing away by a sort of convection.

(2). The specific heat of a given volume of gas varies as its density.

And (3). A law has been discovered by Dulong and Petit, that for most elementary bodies the specific heat is approximately in the inverse proportion of the atomic weight.

With regard to (1), we shall presently conclude that the atoms of which chemists speak are simply the minimum masses into which bodies are, *when in a gaseous state*, broken up by the fluctuations of local density to which they are subjected (see p. 342) ; and we naturally at once connect the existence of the above law with the conclusion of chemists, that equal volumes of gases contain the same number of these atoms.*

The last-named law, if we write "minimum masses"† for "atoms," is evidently in complete harmony with our theory of the formation of minimum masses by the law of symmetrical intermixture, according to which the symmetrical arrangement of one kind of small masses is similar to that of the other kind, and their numbers equal (see p. 11).

We regard the law marked (1), as indicating the probable existence of the following relations :—(a) That different gases at the same pressure provide similar proportions of interstitial space between their minimum masses for the reception of unimolecular ethers driven into or liberated within such gases, and (b) That different gases afford precisely similar facilities for the reception of additional quantities of these ethers.

The existence of the second law above referred to—That the specific heat of a given volume of gas varies as its density—appears to indicate that the quantity of matter in

* The law of Avogadro, of which this is a partial statement, is considered under Chemistry (see p. 358).

† Such minimum masses we shall call *secondary atoms*.



each of the minimum masses of a gas having been once determined when the gas is in a tenuous state, these minimum masses are still kept more or less distinct when it is condensed. For, if this be so, we should expect a given quantity of gas to supply a similar system of interstices between its minimum masses whatever its volume, and that the space afforded by each interstice would vary directly as the volume, and it would follow that if the density of the contained ethers varies as the density of the atoms of the gas, a given quantity of gas would furnish the same facility for the reception of unimolecular ethers among its minimum masses whatever its density, and therefore, for a constant volume of gas, the receptivity for unimolecular ethers would vary as the density.

Next, with regard to the third law:—That for most elementary bodies the specific heat is approximately in the inverse proportion of the atomic weight.

Let us suppose that the two laws of Regnault apply to all simple gases, a supposition which the unity of nature of all matter, indicated by our arguments, evidently countenances.

Then, since from the second of these laws a given quantity of gas has a constant specific heat whatever its density; and equal volumes of different gases taken under the same conditions, contain the same number of chemical atoms; we can deduce from the first law the relation that the specific heats of any two bulks of different gases are in the ratio of the number of atoms they respectively contain.

Now, since equal volumes of the gases of different elements, taken under the same conditions, contain the same number of chemical atoms, the number of atoms contained in *equal weights* of two different gases, is inversely proportional to the atomic weights.

And, therefore, combining these conclusions, for elementary gases we have the identical law whose appli-

cation to solids has been discovered experimentally, *i.e.*, comparing equal weights of the gases of different elements, the specific heat is in the inverse proportion of the atomic weight.

Although, however, experiment has shown the existence of such a law for solids, we have evidence that one of the relations from which we have deduced the same law for gases, does not hold when we pass from the gaseous to the liquid and solid states; for in the passage to these states fluctuations in specific heat occur,* so that the second law of Regnault does not hold.

We may suppose, therefore, that the fact of the probable existence of the same law in connection with both the solid and the gaseous states indicates a probability that *the change in specific heat of given equal quantities of different elements, as they experience change of state, is similar in different elements.*

As an explanation of the facts of the increase of specific heat as a body passes into the liquid state, and of other variations due to change of state, and also of the inapplicability of Regnault's laws to certain gases which are easily condensed, and to compound gases, it is suggested that when a state of considerable mobility is combined with a state of high atomic condensation, and consequent rigidity of minute masses, or when the atoms of a body are some in a condensed state, some in a tenuous state, and the density of some is rapidly changing, while the density of others is continuing practically unchanged, the storage capacity for the unimolecular ethers ceases to preserve the same regularity.

It should be mentioned, however, that when similar chemical compounds are compared among themselves, and

* Such fluctuations occur in compounds. Thus the specific heat of ice is but $\cdot 5040$, as compared with the specific heat of water $1\cdot 000$, and the specific heat of steam is $\cdot 4805$.

not with the elements or with dissimilar compounds, a similar law to that of Dulong and Petit holds good; a fact ascertained by Neumann and Regnault.

To account for the phenomena of latent heat upon the supposition that the unmoolecular ethers are stored in the interstices between the minimum masses of bodies we have only to suppose that the facilities for this storage are different in matter in different states.

Thus to explain how it is that when water passes from the condition of ice to its liquid state, applied heat is not found to raise the temperature until the process of liquefaction is complete, 79·25 units of heat having, it has been calculated, to be expended to liquefy one kilogramme of ice before a rise of temperature begins;—we suppose that when any of the chemical atoms, or secondary atoms, as we shall hereafter call them, of a mass of matter acquire the mobility characteristic of the liquid state a larger space is allotted between them for the storage of the unmoolecular ethers, and consequently that some of the pressure tending to drive the unmoolecular ethers present among the atoms changing their state into the spaces between the remaining atoms is taken off.

And similarly to explain how it is that when water is vaporized the large amount of 537 units of heat has to be expended in vaporizing one kilogramme of water before a rise in temperature begins to be indicated, we suppose that a change to the gaseous state involves a still greater provision of space for the accommodation of unmoolecular ethers.

In harmony with this theory that the phenomena of latent heat are attributable to the different relative amounts of storage room for the unmoolecular ethers furnished by matter in different states, we have the fact that when a change of state occurs *without the application of heat or of cold* phenomena of latent heat appear. Thus :

(1). When water unites chemically with a solid, and the product is solid, we have a rise of temperature.*

(2). When water unites with a gas, and the product is liquid, a great rise of temperature is produced.

(3). When water unites with a solid, and the product is liquid, a fall of temperature is produced.

The causes of changes of state of the nature here referred to will be considered under the head of Chemistry.

We may also mention as direct evidence that the temperature of a body depends on the storage room afforded to the molecular ethers present within it, the familiar experiment of kindling tinder by the heat produced when air is compressed by the sudden forcing down of a piston.

The principles of freezing machines and freezing mixtures furnish interesting examples of heat becoming latent.

In concluding our observations on the subject of heat, we may remark that the *order of fusibility* of different materials appears to depend on the ether conditions prevalent about them. In proof of this we have the fact that in all parts of the world the structure of granite indicates that its quartz, which under all conditions familiar to us is a comparatively infusible material, solidified *after the felspar*, which ordinarily fuses so much more readily.

* We may mention as an instance of the absorption of moisture by a hygroscopic substance producing heat, the schoolboy trick of producing great heat by breathing hard on a coat. The great rise of temperature thus producible has been shown by breathing on a piece of flannel wrapped round the bulb of a thermometer.

CHEMISTRY.

CHAPTER XXXI.

SYMMETRICAL INTERMIXTURE OF THE ELEMENTS.

IN the foregoing pages we have argued that molecular matter is continually undergoing waste, and have endeavoured to show that the various phenomena of electricity, light, and heat are attributable to the return of the ethers forming primary atoms to the unimolecular state; we may remark in entering on the subject now before us that the quantitative analysis of the chemist furnishes no evidence of this waste, the quantity of certain of the elements present in a given portion of matter remaining apparently undiminished though the matter is changed by violent chemical action which involves the occurrence of heat, light, and electrical effects. The explanation of this, which has been already suggested (p. 21), is that the waste caused by atom destruction in the matter around us, great as we conceive it to be, bears a quite inconsiderable proportion to the quantity of molecular matter.

At the outset of an inquiry into the nature and causes of chemical change we may remind the reader of the statement made in the opening pages of this treatise that one of our objects is to show that the complex properties of compounds are the natural and inevitable outcome of the more simple properties of their ultimate constituents,

i.e., of elemental matter. The arguments submitted under the present heading will deal primarily and chiefly with the producing causes of chemical combination only, but, in furtherance of the above object, evidence will from time to time be given, both in the chapters devoted to Chemistry and in subsequent chapters, tending to show that *all the different characteristic properties of all the vast host of different compounds known to us ultimately depend solely on the ether composition of these compounds*; differences in ether composition appearing adequate to account for those differences of state, of chemical affinity, of physical properties, of stability, etc., manifested by different bodies under like conditions, and to which the different effects produced by these bodies on one another and on our sensory organs are attributable.

In turning our thoughts to the subject of chemical combinations we notice first that there is one particular feature of them, distinguishable in all their varied kinds, which suggests that the law of symmetrical intermixture is always a factor of such combinations. We allude to the fact of the homogeneity of chemical compounds—that the smallest distinguishable particles of any compound contain all the different elements entering into the compound; for this evidently indicates that one necessity of chemical combination is complete intermixture of the combining elements brought into juxtaposition.

Let us in the first place consider what is likely to be the nature of the intermixture which is thus seen to be a necessary factor in chemical combination, leaving for subsequent consideration the causes of the changes of state and other changes which constitute chemical action.*

* The different properties of bodies not connected with their chemical action on one another, as hardness, malleability, brittleness, etc., will be referred to under a different section of this treatise after the phenomenon of crystallization has been explained.

From the arguments previously offered as to symmetrical intermixture, and as to the nature of the different states of matter, we conclude that two kinds of *symmetrical* intermixture of the elements, or different kinds of *molecular* matter, are conceivable :—(a) a symmetrical intermixture of two gases ; (b) a symmetrical intermixture of two liquids.

The familiar cases of intermixture *not productive of chemical combination* furnished respectively by the spontaneous intermixture of gases, and the diffusion of liquids (p. 38) we naturally suppose, as already intimated, to be instances of these two kinds of symmetrical intermixture. For example, to account for the fact of the oxygen and nitrogen and small quantities of other gases, forming the atmosphere, being all thoroughly mixed together, instead of being arranged in layers around the earth in the order of their specific gravity like water and oil in a vessel, we suppose that waves of alternating compression and expansion, traversing all parts of the atmosphere,* produce a continual rearrangement of the minimum masses of its various constituents in obedience to the law of symmetrical intermixture.† And we further suggest that the formation

* See p. 24. For the law of symmetrical intermixture to operate it is necessary that the intermixing substances have different degrees of compressibility, in other words that they do not strictly follow the law of Boyle. We have already seen (p. 38) that gases when highly compressed do not strictly follow this law, and we may suppose that they are highly compressed locally at points where waves have their maximum effect.

All matter, we have concluded, is continually being tossed by unseen waves, fluctuations of ether pressure occurring everywhere throughout the universe, out from the massed glories of the heavens visible to us as far as the faintest gleam of star-suns can penetrate.

† How completely the intermixing forces of the law of symmetrical intermixture overcome gravitation, even when the gases intermixing have widely different specific gravities, is shown by

of alloys, as well as cases of the solution of one liquid in another, furnish examples of the symmetrical intermixture of liquids.*

We shall find the supposition in harmony with our subsequent arguments as to the nature of chemical action that the first of the two kinds of symmetrical intermixture of two different elements we have thus referred to, *the intermixture of gases, and that only, is the kind of intermixture which is the necessary factor in all cases of chemical combination.* In other words while intermixture of gases may, as we may have seen, occur without any combination taking place, it will appear from our arguments that no case of chemical combination, as defined by chemists,† ever takes place without the combining bodies passing into the gaseous state, if only for an infinitesimal period of time, *during the process of com-*

the familiar experiment of connecting a jar containing hydrogen with a jar containing oxygen by a long narrow tube and *placing the oxygen jar lowest*, for when this is done it is found that after a little while both jars are filled with a similar mixture of the two gases.

* Cases of the absorption of gases by liquids, *e.g.*, the absorption of atmospheric air by water, may be regarded as coming under the head of the solution of one liquid in another if we suppose the gas to become liquid as it enters the liquid which absorbs it. Cases of the solution of solids, *e.g.*, of sugar in tea, of chalk in water, of shellac in alcohol, of gun-cotton in ether, may similarly be placed under the same head if we suppose the solids to become liquid on entering the liquid in which they dissolve.

There are cases of solids taking up gases (*e.g.* platinum occludes hydrogen), and of their taking up liquids (*e.g.* solid glue absorbs water), which are to be explained in a very similar way, but in these cases the arrangement of the small masses of the two constituents in the mixture produced is, perhaps, not so symmetrical as when two liquids are intermixed.

† There are, it may be noticed, slight alterations of temperature, and molecular changes, attending the formation of alloys which are analogous to those accompanying chemical changes.

combination,* and intermixture occurring while they are in this state.

A telling piece of evidence in favour of this supposition is that, if we compare the volumes the elements and their compounds occupy in the state of gas at the same temperature and under the same pressure, it is found that gases always unite chemically *in very simple proportions*, viz., either in equal volumes, or in volumes which bear some simple relation such as 1 : 2, 1 : 3, 1 : 4, 2 : 3, etc., and whatever the number of such volumes before combination, it always is reduced to two on combination.

Thus one volume of oxygen combines with two similar volumes of hydrogen to produce water, and, if the combination takes place under such conditions that the product is vapour, there are two of these volumes of this vapour.

In favour of the above supposition we may also urge the following :—

The theory and notation of modern chemistry are based on the two suppositions—(1) That the matter of each of the elements has ultimate particles incapable of subdivision, or atoms, possessing definite weight proper to this element ; (2) That equal volumes of all substances, when in the state of gas and under like conditions, contain the same number of atoms or molecules.† And the facts

* Even if immediately before chemical combination the bodies combining are solid, or liquid, and the body which results is found to be solid or liquid immediately after combination, we suppose that the combining bodies were in the gaseous state at the instant of combination.

That even such an involatile body as carbon may pass into the gaseous state in reactions in which it takes part appears from the fact that the vapour density of carbon monoxide is such as to require the gaseous expansion of the carbon as well as of the oxygen to account for it.

† This is named after its proposer, “The law of Avogadro.” A law almost precisely equivalent to it expressed in the terms used in this treatise is deducible (see p. 358).

to which these suppositions principally owe their origin are, the definiteness of the proportions in which, in all cases, the elements unite, and the simple relations, to which we have alluded, prevailing between the gaseous volumes in which they unite.

Now the suppositions just referred to may be stated in terms of our theories if we suppose *that the units, or atoms, of modern chemistry relate to the gaseous state and are practically nothing more nor less than the units, or "minimum masses," of a gaseous mass in which symmetrical intermixture is taking place* (which minimum masses we shall call *secondary atoms*).^{*} And that in cases where *equal* volumes of two gases unite chemically the intermixture which occurs is simply a case of symmetrical intermixture, of the nature described in the early part of this treatise, of *equal numbers* of two kinds of minimum masses; the two equal volumes which combine consisting therefore of equal numbers of minimum masses or secondary atoms.

We shall in the following pages submit a theory of the way in which the law of symmetrical intermixture accomplishes the distribution of minimum masses, or secondary atoms of one element among minimum masses, or secondary atoms of another *in the various proportions in which the atoms of the modern chemist occur in chemical compounds*, but before we attempt this it will be convenient to devote a chapter to the subject of chemical symbols and technical terms.

^{*} Each secondary atom will thus consist of a number, probably a very large number of primary atoms, some of which will be expanded, some highly condensed when the secondary atom is in the gaseous state.

CHAPTER XXXII.

CHEMICAL SYMBOLS AND TECHNICAL TERMS.

AS the ordinary chemical symbols are employed in this treatise, the information usually given in text books respecting the notation of modern chemistry is, for the convenience of readers who may not be familiar with this branch of science, incorporated in the present chapter.

Modern chemical notation expresses the proportions in which the different elements enter into various compounds in terms of the atoms of the elements. Thus H_2O , the symbol of water, signifies that the number of atoms of hydrogen in this compound is double the number of oxygen atoms; in other words that each molecule or unit* of a mass of water consists of 2 atoms of hydrogen, 1 of oxygen.

If, as we have suggested, the atoms here are the minimum masses of the elements combining, formed in the gaseous state prior to combination, and these minimum masses are of equal magnitude under like conditions, it is evident that chemical symbols will also express the proportions of the elements measured as gases which are present in a compound, *e.g.*, H_2O expresses the fact, already alluded to, that two volumes of hydrogen combine with one volume of oxygen to produce water.†

* We may call these units which are composed of secondary atoms *secondary molecules*.

† As will appear presently, the universal application of the conclusion that the atoms are minimum masses of gas, on which

The placing of a figure before a symbol or formula, as 5HOH , signifies that it applies to all the letters which immediately follow : thus the formula which we have just written would mean 5 molecules of water consisting of 10 atoms of hydrogen and 5 of oxygen.

As it is argued subsequently that the fact already alluded to, that whatever the number of gaseous volumes before combination there are never more than two after combination, is due to two kinds of atoms only expanding in each molecule, and, as it will be convenient in some cases to indicate which are believed to be the expanded atoms in a particular case, the plan will be adopted of putting the letters symbolizing atoms which are believed to be those to which expansion of the mass is due, in larger type when attention is to be called to them. Thus **HOH** would indicate aqueous vapour whose gaseous state is believed to be due entirely to the expansion of the hydrogen atoms.

The atomic weight of each element is the proportion which the weight of its atom, *i.e.*, according to the view we have submitted, the weight of one of the minimum masses of its gas, bears to that of a hydrogen atom or minimum mass ; the latter being taken as unity.

The table, on the following page, gives the relative atomic weights of the various principal elements, taking hydrogen as unity, as far as our present knowledge furnishes us with them. It should be noted, however, that further research may lead to a different estimation in some cases.*

this depends, will necessitate the adoption of some changes in the table of the atomic weights of the different elements generally accepted.

* This table is taken from the Article on "Chemistry" in the "Encyclopædia Britannica," with one or two exceptions which are noted, and the reason for divergence stated.

TABLE OF ATOMIC WEIGHTS OF THE PRINCIPAL ELEMENTS.

<i>Name of Element.</i>	<i>Symbol.</i>	<i>Atomic Weight.</i>
Aluminium . . .	Al	27·3
Antimony . . .	Sb (Stibium)	122
Arsenic . . .	As	149·8*
Barium . . .	Ba	136·8
Bismuth . . .	Bi	207·5
Boron . . .	B	11
Bromine . . .	Br	79·75
Cadmium . . .	Cd	111·6
Calcium . . .	Ca	39·9†
Carbon . . .	C	11·97
Chlorine . . .	Cl	35·36
Chromium . . .	Cr	52·4
Cobalt . . .	Co	58·6
Copper . . .	Cu	63·3
Fluorine . . .	F	19·1
Gold . . .	Au (Aurum)	196·2
Hydrogen . . .	H	1
Iodine . . .	I	126·53
Iron . . .	Fe (Ferrum)	55·9
Lead . . .	Pb (Plumbum)	206·4
Magnesium . . .	Mg	23·94
Manganese . . .	Mn	54·8
Mercury . . .	Hg (Hydrargyrum)	99·9‡
Nickel . . .	Ni	58·6
Nitrogen . . .	N	14·01
Oxygen . . .	O	15·96
Phosphorus . . .	P	61·92§
Platinum . . .	Pt	196·7
Potassium . . .	K (Kalium)	39·04
Silicon . . .	Si	28
Silver . . .	Ag (Argentum)	107·66
Sodium . . .	Na (Natrium)	23
Strontium . . .	Sr	87·2
Sulphur . . .	S	31·98
Tin . . .	Sn (Stannum)	117·8
Zinc . . .	Zn	64·9

* The vapour density of arsenic indicates that, according to the above arguments, it has double the atomic weight usually attributed to it, which is 74·9.

† Some reasons will, however, be stated in the chapter on Crystallization for the belief that Calcium has but half this atomic weight, *i.e.*, 19·99.

‡ The vapour density of Mercury indicates this atomic weight rather than 199·8, the atomic weight usually given.

§ The vapour density of Phosphorus indicates this atomic weight rather than 30·96, the atomic weight usually given (see p. 354).

The percentages of various elements in a body are evidently calculable from its formula by multiplying the number of atoms of each constituent element by the corresponding atomic weight, and taking the products thus obtained successively as numerators, and their sum as the common denominator, and then reducing the fractions thus formed to a denominator of 100.

The presence of the + sign between symbols signifies that the molecules they represent are brought into contact, but does not necessarily indicate the production of a higher chemical compound.

The meaning usually attached to the sign = is that from such and such bodies such and such other bodies are formed.*

The grouping of the letters between brackets, or periods, in the formulæ of more complicated compounds, as $\text{L}_2\text{SO}_4\cdot\text{OH}_2$ (formulæ so written being generally called constitutional formulæ), signifies a belief that a closer union prevails between the atoms indicated in the same section or period than between those in different sections ; that there is, in some sense, a number of molecular groups within a single molecule.

Perhaps the most direct evidence of the existence of the state of things thus represented is furnished by what are known as *polymerism* and *isomerism* ; the former is a term used to express the phenomenon of the existence of two or three compounds which are precisely identical in their atomic composition so far as the proportions of their constituent atoms are concerned, but differ from each other either in their chemical behaviour or physical pro-

* It may be remarked to the casual reader that this symbol must not be treated as though it were an ordinary algebraical symbol ; it is only useful for expressing ascertained facts, and not as a means of ascertaining them : in other words we cannot work out new chemical equations by the mere manipulation of symbols.

perties; and isomerism is a particular case of polymerism, in which the vapour density of the similar combinations is the same.

A familiar example of the latter is afforded by propionic acid, methyl acetate, and formic ether, all three of which are alike represented by the formula $C_3H_6O_2$. They are all liquids, they yield vapours of the same density, the latter two have nearly the same boiling point and specific gravity as liquids; but there is no doubt of their distinct existence.

We seem, in such a case as this, shut up to the conclusion that the atoms in the molecules are broken up into two or three groups, the grouping being different in each of the three different cases.

With regard to technical phraseology.

A *reaction* simply means the mutual or reciprocal action of chemical agents, whether elements or compounds, on each other.

Of the three classes of reactions—*synthesis*, *analysis*, and *metathesis*—

Synthesis is the production of chemical compounds, either from the union of elements, or of simpler compounds.

Analysis, the converse of synthesis, is the splitting up or resolution of compounds into the “elements” of which they are composed, or into simpler compounds.

Metathesis is an exchange of atoms effected between two compounds, of such a nature that each unit or secondary molecule of one of the compounds parts with a certain atom, or with certain atoms, to one of the units of the other compound, and receives in substitution a certain atom, or certain atoms, from one of these units.

CHAPTER XXXIII.

ADEQUACY OF THE LAW OF SYMMETRICAL INTERMIXTURE
TO PRODUCE VARIOUS KINDS OF ATOM COMBINATION SUCH
AS OCCUR IN DIFFERENT CHEMICAL CHANGES.

IN this chapter it is proposed to indicate the manner in which the law of symmetrical intermixture, acting on variously constituted gases, is competent to produce arrangements or rearrangements of the atoms of the different elements just such as are actually presented when a chemical change, whether a synthesis, an analysis, or a metathesis takes place.

And first as to the synthesis, or building up of intermixtures of the elements by the operation of this law.

Deferring, for the moment, the question of how compounds come to have their atoms in different states of expansion under different circumstances, it is evident that, arguing from the conclusions reached in this treatise as to the behaviour of primary atoms (p. 18), we can conceive a mass of symmetrically intermixed secondary atoms of two kinds to have under different conditions.—

(a) Both kinds of atoms highly condensed—*i.e.*, solid or liquid.

(b) One kind highly condensed, the other greatly expanded.

(c) Both kinds greatly expanded.*

* If the degree of expansion of a mass of atoms in the condition marked (c) is as great as the degree of expansion its components had at the time the symmetrical intermixture was taking place, it

Or finally (*d*), some only of one, or both kinds greatly expanded, the rest of the atoms highly condensed.

Of the first case, in which the compound produced is solid, or liquid, it is suggested that we have examples in the normal condition of some of the monoxides of the metals, and several salts of potassium and sodium.

The remaining three cases, according to our previous conclusions, are examples of the gaseous state.

The following compounds, it is suggested, furnish examples of a gaseous state of the kind marked (*b*) ; * Sulphur chloride, ClS, or as it is commonly written Cl₂S₂, Selenium chloride, ClSe, Cyanogen, CN, Ethine, or Acetylene, HC.†

seems clear that the stability of the intermixture must be very small ; but if the degree of expansion of both kinds of atoms is, although considerable, much less than that which prevailed when they were intermixing the stability will it is evident be far greater, since in this case the magnitude of minimum masses of the intermixed mass will, so long as such greater density prevails, exceed the magnitude of the secondary atoms intermixed, and in consequence of this, the internal motions which are continually tending to separate particle from particle will not be able to separate any portion of the mass into distinct atoms. We shall, in accordance with this conclusion, suppose that where two gases *combine chemically* without a permanent diminution of bulk occurring, the gases were much expanded at the time of the intermixture and contracted again afterwards to their original bulk, and that if expansion as great as that at which intermixture thus took place were produced we should, instead of chemical combination, have mere intermixture, as in the case of the different gases composing our atmosphere.

Some confirmation of this view will be offered presently when we come to deal with the causes of the changes of bulk and of state which accompany chemical reactions.

* According to our previous conclusions this will, however, not be the only gaseous state possible for the compounds named ; we must suppose that under favourable circumstances of high temperature or otherwise, every compound will pass into the gaseous state marked (*c*).

† To these must probably be added Mercuric chloride, generally written HgCl₂, but which, if the atomic weight we have stated for mercury is correct, when gaseous, should be written HgCl.

The reason we suppose these compounds, when gaseous, to be in this state is that, as atoms which are in the solid or in the liquid state occupy an inappreciable amount of space as compared with highly expanded gaseous atoms, compounds of two elements in the gaseous state marked (b) may be expected to have half the bulk, practically, of the gaseous elements composing them, when the external conditions are the same—*i.e.*, the two equal volumes of the combining elements furnish one similar volume of the compound.

It is suggested next that the following compounds furnish examples of a gaseous state of the kind marked (c):—Nitric oxide, NO, Carbonic oxide, CO, Hydrogen chloride, HCl, Hydrogen bromide, HBr, Hydrogen fluoride, HF. In this case two equal volumes of the combining elements produce two similar volumes of the compound.

The remaining kind of gaseous state (d) has probably comparatively few examples. Its occurrence is, it is suggested, to be attributed to the presence of two or more different kinds of atom groupings in the same mass, the proportions of the two elements which are present in the different groups of atoms being so related that when the numbers of atoms respectively present are added together the total number of one kind of atom is the same as the total number of the other, the compound thus coming under the case we are considering.

This view receives support from the fact that cases which fit our conception of the kind of gaseous state marked (d) are found among polymeric compounds.* Thus equal numbers of carbon and hydrogen atoms, CH, are found not only in the compound *acetylene*, generally written C_2H_2 , which appears by its vapour density to offer an example of the kind of gaseous state we have marked (b), but also in *benzene*, generally written C_6H_6 , which appears by its vapour density to have when in the

* As to polymerism, see p. 346.

gaseous state but one atom expanded in three molecules CH ; in *styrolene*, generally written C_8H_8 , which appears by its vapour density to have when in the gaseous state but one atom expanded in four molecules CH ; and finally, in *dihydronaphthalene*, generally written $C_{10}H_{10}$, which appears by its vapour density to have when in the gaseous state but one atom expanded in five molecules CH.

Again, two-atom combinations in some of the states above conceived, whose existence we have thus shown probable, are, according to our previous conclusions, capable, like the elements, of taking part in symmetrical intermixture, *i.e.*, a compound in the state marked (b), or in the state marked (d), if in the latter state it has but one* kind of atom expanded, is open to symmetrical intermixture, of the kind which has been described, with a gaseous element, or with another gaseous compound.

The mass which results will have, *at the moment after intermixture is achieved*, two atoms of each molecule expanded, which atoms will be arranged in space approximately in one of the two symmetrical systems for equal numbers of two kinds of bodies previously described (p. 11) ; the remaining atoms will be condensed, and arranged, probably with almost as great a degree of symmetry, between the expanded atoms much in the same way as we have pictured the condensed atoms of expanded primary molecules to be arranged (p. 16).†

In the case of intermixture of a compound in the state marked (b) with an element, we evidently get three-atom

* The law of symmetrical intermixture we suppose produces symmetrical intermixture of *but two* kinds of minimum masses at the same place and time (see p. 355).

† The freedom of movement characteristic of gases will of course cause any symmetry of arrangement produced to be only approximate at any given moment, *i.e.*, the atoms are to be pictured as in continual motion, while having their mean positions symmetrically situated in space.

molecules, and we observe that a mass of molecules thus arrived at may be conceived to have, under different conditions—

(A) All three atoms in each molecule highly condensed.

(B) One atom greatly expanded, two atoms highly condensed.

(c) Two atoms greatly expanded, one atom highly condensed.

The case of three atoms greatly expanded is inadmissible, since it would involve an infraction of the law that, whatever the number of volumes of gas before chemical combination occurs, the number is always reduced to two on combination (see p. 341). We shall offer a reason presently (p. 355) why there cannot be more than two atoms of different kinds highly expanded in each molecule, and thus account for this law.

Again, symmetrical intermixture can be conceived to occur between a three-atom compound in the state (B) or one in the state (c) (if the two expanded atoms are of the same kind), and a gaseous element, or another gaseous compound.

In the case of intermixture between a three-atom compound in the state marked (B) and a gaseous element we get four-atom molecules, and a mass of molecules thus arrived at may be conceived to have, under different conditions—

(α) All four atoms in each molecule highly condensed.

(β) One atom greatly expanded, three atoms highly condensed.

(γ) Two atoms greatly expanded, two atoms highly condensed.

As before, cases of more than two kinds of atoms greatly expanded will be inadmissible.

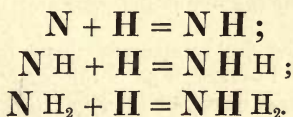
Again, we may conceive intermixture of a mass of four-atom molecules with a gaseous element or with another

gaseous compound to take place, and, if any resulting compound passes into a gaseous state in which but one kind of atom is greatly expanded, this intermixture may, in like manner, be followed by another, and so on, until a compound is reached whose state does not admit of further intermixture.

It is evident that in this way masses of intermixed atoms of a great degree of complexity of atom composition may be conceived to be produced by a succession of symmetrical intermixtures, and based on this :—

The theory of chemical synthesis here offered is that every compound, however complex, owes its atom composition to a series of acts of successive symmetrical intermixture, in other words, that every complex compound is the offspring of simpler compounds and is ultimately descended from a compound whose molecules contain but two atoms.

Thus, to take a simple instance, when the compound, ammonia, NH_3 , is formed directly from its elements by submitting a mixture of the two gases, nitrogen and hydrogen, to the action of the silent electric discharge, we suppose that the following acts of intermixture occur in immediate succession wherever the compound is formed :—



And the explanation offered of the fact that in this, and in very many other kindred cases we have no evidence of the existence of the series of compounds which, according to this view, must have been produced as stepping stones to the production of the compound known to us, is that the state of these simpler compounds immediately on

their production was such that they invited further symmetrical intermixture.*

We shall refer presently to some probable causes of the changes of state of the molecules forming steps in such a process from the condition of full gaseous expansion we have supposed them to have immediately after their formation to the condition of half-expansion necessary, according to the above theory, to prepare them for further symmetrical intermixture,—*e.g.*, a change of a two-atom molecule from the state we have marked (c) to that marked (b) (see p. 370), or a change of a three-atom molecule from the state we have marked (c) to that marked (B).†

While on the subject of the synthesis of compounds through the agency of symmetrical intermixture we will suggest how combinations are obtained whose molecules, if written so as to be in harmony with the law of Avogadro (*i.e.*, so as to contain but two *expanded* atoms), and so that the atomic weight of the constituents is based strictly on the vapour density, *contain half-atoms*. We have examples of molecules in which this is the case in some of the compounds of phosphorus, if we write the atomic weight of this body according to its vapour density.

We remarked just now that if two atoms which are expanded in each of the three-atom molecules composing a given mass *are of the same kind*, symmetrical intermixture

* Some cases of chemical compounds which give support to these views will be referred to further on in this chapter. In particular we may note the fact of a limited supply of oxygen causing the production of *carbonic oxide*, CO, a more copious supply the production of *carbonic dioxide*, CO₂.

† It may be remarked that our theory of the origin of change of state leads us to conclude that when a molecule passes from the solid or liquid state to the state of complete gaseous expansion in which two atoms are expanded in each molecule, or *vice versâ*, it must in every case be found during some period of the change, infinitesimally short it may be, in the intermediate state in which but one atom in a molecule is expanded.

may occur with a gaseous element, or with another gaseous compound. Now, taking the case of intermixture with an element, it is evident that in order to have an intermixture containing equal numbers of *expanded* atoms of two different kinds, two atoms of the element will be requisite for every three-atom molecule containing two expanded atoms, and that in the resulting five-atom molecule we shall have at the moment of intermixture four atoms expanded—two of one kind, two of another. And therefore if we follow the usual practice and consider that each molecule must have but two expanded atoms we shall write the molecules of such a gaseous compound in the form $A\frac{B}{2}$, or $A\frac{B}{2}C$, *i.e.*, so that each molecule contains two and a half atoms.

It is evident we can as readily conceive further combination to occur with molecules of this kind as with molecules whose symbols contain whole atoms only.

Next as to the analysis, or breaking up of complex atom combinations through the operation of the law of symmetrical intermixture.

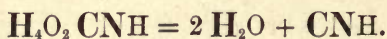
If a body composed of molecules containing more than two atoms passes beyond the gaseous state in which two atoms in a molecule are expanded to a state in which three or more atoms are expanded, we should evidently look for a loss of equilibrium under the changes of pressure to which the law of symmetrical intermixture is due, and for a breaking up of the mass into smaller masses, each consisting either of one kind of *expanded* atoms only or of two different kinds of expanded atoms in equal numbers.

And in harmony with this it is suggested that the origin of the law already referred to, that, whatever the volumes of different gases combining, it is always reduced to two on combination—or, as we should express it, that a compound cannot have more than two kinds of atoms greatly ex-

panded—is that, when in any given mass equal numbers of two kinds of atoms are already expanded, the expansion of more atoms is always productive of the breaking up of the compound into simpler forms.

Thus in the case of the higher chloride of phosphorus, PCl_6 ,* (or $\frac{\text{P}}{2}\text{Cl}_5$) being readily resolved into the lower chloride, PCl_5 , and chlorine by the application of heat, it is suggested that the change is due to the rise of temperature producing a gaseous state of the higher chloride in which six atoms are expanded,—i.e., a state which, according to the scheme of notation above proposed (p. 344), would be written PCl_5Cl_5 , and that the law of symmetrical intermixture acting on this unsymmetrical gas breaks it up into a symmetrical gas of the lower chloride, and chlorine.

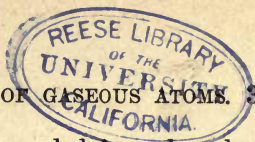
As an example of the very common form of analysis known as dehydration, to which the explanation just given applies, we have the conversion of ammonium formiate, $\text{H}_5\text{O}_2\text{CN}$, into hydrocyanic acid and water by the action of heat. Probably the process is expressed by the equation



As another example of analysis to which also a similar explanation applies. Potassium chlorate, KClO_3 , if heated decomposes, first yielding a mixture of potassic perchlorate KClO_4 , potassic chloride, KCl , and oxygen, but ultimately being entirely resolved into potassic chloride and oxygen.

Here it is suggested that, on the rise of temperature of the mass causing some portions of it to vaporize, different states of vapour expansion are, owing to slight differences of condition at different points, simultaneously produced, and that thus we have side by side, a state of semi-expan-

* Phosphorus is taken to have double the atomic weight usually stated (see p. 345).



sion in which one atom only is, expanded in each molecule KClO_3 , and a state of dissociation in which, all the atoms being expanded, the mass breaks up into potassic chloride, KCl , and oxygen; that the law of symmetrical intermixture causes the molecules of chlorate which have but one atom only expanded to intermix with atoms of oxygen liberated from the dissociated molecules, and that thus we get at first the perchlorate KClO_4 , but that a higher temperature dissociates the molecules of perchlorate by expanding all their atoms so that the whole mass is resolved into potassic chloride* and oxygen.

As an example of analysis in which the sudden expansion of the atoms of a compound to the gaseous state is evidently associated with the dissociation of the atoms we have the fact that iodide of nitrogen (a black powder obtained by digesting iodine for half an hour in a cold solution of ammonia), explodes upon the slightest touch, indeed often without assignable cause. The explosion is remarkably sharp and sudden; fumes of iodine are produced and a faint light is emitted.†

The kind of chemical analysis known as electrolysis will receive a different explanation from that just given of ordinary cases of analysis (see p. 389).

According to the views here propounded, any atom in a mass, whether the mass is solid, liquid, or gaseous, is equally related to all the atoms similar to one another which touch it, and when we talk of a molecule we do not mean a group of particular individual atoms, but merely an undivided unit of mass which contains the proper proportions of the different kinds of matter composing the different atoms; our views are therefore not precisely in accord with the conception generally understood by the law of Avogadro,

* For the reason of the atoms of potassium and chlorine pairing together, see p. 358.

† The subject of explosions is considered subsequently.

“that equal volumes of all substances when in the state of gas and under like conditions contain the same number of molecules.”

If, however, in deference to the law just referred to, the practice is followed of so writing the symbols of molecules that each shall contain two expanded atoms when the mass is gaseous, it is evident that as the result of the equality prevailing between minimum masses of different gases to which allusion has already been made, and neglecting the occupation of some small amount of space by the atoms remaining condensed, we have the following law covering much the same ground as that covered by the law of Avogadro.

Equal volumes of all substances when in the state of gas and under like conditions contain approximately the same number of expanded secondary atoms.

Finally let us endeavour to explain the interchange of atoms occurring in metatheses.

We may either suppose that the compounds which effect an interchange of atoms have at first each only one atom in a molecule expanded, and that the first step is the production by symmetrical intermixture of complex molecules composed of all the atoms of both original compounds, and that directly upon this combination occurring more atoms expand, whereupon, according to the law just referred to above, the compound, which has thus become unsymmetrical, breaks up, different atoms from those formerly united now pairing together. Or we may suppose, which seems very likely, that the first step is that *local* intermixture of all the atoms which must, it is evident, take place wherever the boundaries of gaseous masses of the original compounds come in contact, even though these compounds are in the gaseous state produced by expansion of two kinds of atoms.

As to the origin of differences of chemical affinity that determine in each case which atoms shall group together

when, as just supposed, the law of symmetrical intermixture breaks up an unsymmetrical mass (*i.e.*, a mass in which more than two kinds of atoms in equal numbers are expanded) into patches of symmetrical composition—*i.e.*, into masses which have two kinds of atoms in equal numbers expanded, we suppose :—

That, since any given change of pressure will evidently produce more vigorous movements in a small mass to which it is applied *the greater the difference in their readiness of compression of the different kinds of atoms in contact* (see p. 9), we shall in all cases have those of the expanded atoms which differ most in readiness of compression pairing together and, generally, *the nature of the distribution of the expanded atoms of different kinds will be regulated by their relative readiness of compression, certain definite groups of these atoms being therefore formed in each particular case.*

Further, that, *as to the distribution of those of the atoms concerned in any metathesis which continue highly condensed during the process, these atoms will follow the destination of those of the expanded atoms between which and them the greatest and most unbroken cohesion subsists.*

It would appear, however, that there are some few exceptional cases in which the condensed atoms are thrown down from the changing mass in an uncombined state. As probable instances we may refer to the cases in which the metal silver is thrown down from its compounds. In these cases we suppose that the atoms of silver are those which remain condensed when the compound becomes gaseous, and that the silver forming these atoms is aggregated together and, as it were, shaken out of the mass in the condensed state* :—For example, when hydrofluoric acid is obtained by heating silver fluoride in an atmosphere of hydrogen, we suppose that the metathesis is not due to expanded fluorine atoms mixing more readily with expanded hydrogen atoms

* See as to this conception our theory of electrolysis, p. 391.

than with expanded silver atoms, but to the production of an unstable compound, FAgH , of which at the moment of production the fluorine and the hydrogen atoms are expanded, and that the condensed silver is as it were shaken out of this compound while the gaseous state continues—that, to express it in our notation,



It may perhaps be supposed to favour the theory above submitted of the cause of the particular grouping of the atoms produced in most cases of metathesis, that we commonly find those elements pairing together whose places in the electro-chemical series (see p. 393) are furthest apart, *i.e.*, those which presumably differ most in ether composition and readiness of compression. Some simple cases of metathesis, to which we shall presently refer, will be found to exemplify this.

In some cases of metathesis we have evidence that, as above suggested, the first step in the process is the formation of complex molecules containing all the atoms of both compounds concerned in the reaction.

Thus hydrogen chloride, HCl , combines directly with sulphuric anhydride, SO_3 , to form sulphuric chlorhydrate, and it is only when the latter is heated in a closed vessel to 170°C . that we get it decomposed into sulphuric chloride Cl_2SO_2 , and sulphuric acid, H_2SO_4 .

The atoms expanded when the law of symmetrical intermixture accomplishes the synthesis first referred to are probably those indicated thus—



and those expanded when the subsequent analysis which completes the metathesis occurs, thus—

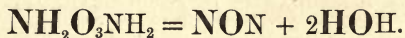


The fact of the division of the sulphur atoms between the two compounds thus ultimately produced may possibly be due to their being, as we shall presently conclude the atoms of oxygen in ozone are (p. 367), in two different electrical states, one-half in a more positive and the other half in a more negative state, and to the more positive atoms going to one compound, the more negative atoms to the other.

It would appear, according to the above theories, that in many cases of analysis the atoms which remain condensed during the process are divided, some following the destination of one kind of expanded atoms, some the destination of another kind ; although generally *the same kind* of atoms do not appear to be divided, as we have supposed they are in the case just referred to.

As a probable example of the division of the atoms which remain condensed, ammoniac nitrate when gently heated is resolved into a mixture of the vapours of nitrous oxide and water.

According to the theories above submitted we suppose this change to be due to more than two atoms in a molecule becoming expanded, and the unsymmetrical gas thus produced breaking up into symmetrical gases, *the atoms which remained condensed, some following the destination of one kind of expanded atoms, some that of another*. Probably the process would be expressed by this equation—



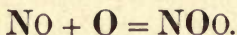
It affords some experimental support of the above theories, that in several cases where compounds are known to us such as would be intermediate steps in the formation of complex compounds in the manner supposed, we find some interesting facts showing the existence of connecting links between different compounds belonging to the same series.

Thus in reference to the several known compounds of nitrogen and oxygen :—

The simplest of these compounds is *nitric oxide*, NO, a gas having normally the same volume as its uncombined constituents, and the formation of which, according to the above, we suppose to have been preceded by a symmetrical intermixture of the gases oxygen and nitrogen in equal quantities.*

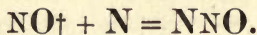
When this gas is mixed with oxygen it immediately combines with it in the volume proportions 2 : 1 and we get a second compound, *nitric peroxide*, NO₂.

This atom combination is explained in harmony with the above theory if we suppose that in the presence of oxygen one atom in each molecule NO becomes condensed, and that thereupon the symmetrical intermixture follows between equal volumes which is expressed by the equation



Further the compound NO₂ is known to us in two gaseous states, both in harmony with our theories; for at low temperatures its volume agrees with the conception that but one atom out of the three composing each molecule is expanded, but when heated its volume increases faster than would normally be the case till at 150° its volume agrees with the conception that two atoms out of three are expanded.

Nitrous oxide, N₂O, we should suppose to be derived from a symmetrical intermixture between nitric oxide and nitrogen,



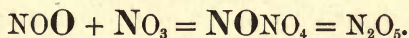
* A reason has already been suggested (see note *, p. 348) why in some cases an intermixture of this kind is followed by chemical union, and in other cases is not so followed. The cause of chemical union is more fully treated, p. 370.

† We suppose therefore that under one set of conditions gaseous nitric oxide has only its nitrogen atoms expanded, and under another set of conditions only its oxygen atoms expanded, under normal conditions both its nitrogen and its oxygen atoms expanded.

Then we have *nitrous anhydride*, N_2O_3 , apparently produced together with nitric peroxide, NO_2 , when nitric oxide is mixed with oxygen, and this compound we may suppose is derived from a symmetrical intermixture between nitric oxide, NO , and nitric peroxide, NO_2 , when each of these has but one atom in a molecule expanded.

And finally we have the unstable compound, nitric anhydride, N_2O_5 , whose transparent prismatic crystals melt at about $30^\circ C.$, and which gradually decomposes even at ordinary temperatures into oxygen and nitric peroxide; and this compound we may suppose to be the result of symmetrical intermixture between nitric peroxide, NO_2 , and groups of atoms, NO_3 , when both these groupings have but one atom expanded in a molecule.

Thus—



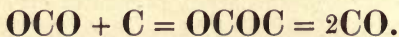
Again, as to the two compounds of carbon and oxygen known to us,—*carbonic oxide*, CO , and carbonic dioxide, CO_2 ,—both of which in their normal condition have a degree of gaseous expansion which leads us to suppose that two atoms are expanded in each molecule.

Favouring our view that the atom combination presented by carbonic dioxide, CO_2 , is due to symmetrical intermixture between carbonic oxide, CO , when in the state marked (*b*) in which one atom is expanded (p. 348) and oxygen, we have the fact that carbonic oxide is formed when the supply of oxygen is small.

As possibly connected with the supposed difference of structure of the two gases—that carbonic oxide has no atoms condensed, while carbonic dioxide has one atom in a molecule condensed—we may refer to the different behaviour of the two gases. Thus carbonic oxide is combustible producing carbonic dioxide ($CO + O = CO_2$); carbonic dioxide is not combustible, and will not support combustion.

Carbonic oxide is extremely poisonous being capable of displacing the oxygen in the blood ; carbonic dioxide is merely inert.

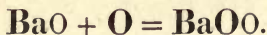
When carbonic dioxide is passed over red-hot carbon, carbonic oxide is produced. Probably the vapour conditions prevalent at the moment when the change takes place are represented by the equation



Next, as to the two oxides of barium, *barium oxide*, BaO , and *barium dioxide*, BaO_2 , we have the significant facts that the higher oxide, BaO_2 , *when strongly heated*, gives up one-half of its oxygen and produces the lower oxide, BaO ; and that the latter is reconverted into the dioxide when it is gently heated and moist air passed over it.

Evidently our theory of the production of barium oxide and oxygen from strongly heated barium dioxide would be that the latter comes to have three atoms in a molecule highly expanded, and that the unsymmetrical gas thus produced is by the law of symmetrical intermixture broken up into the symmetrical gas, **BaO**, and oxygen.

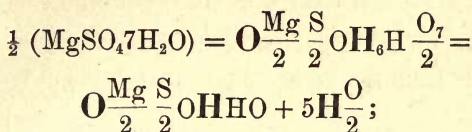
And the production of the atom arrangement presented by the dioxide from gently heated barium oxide, BaO , and oxygen we should suppose to be due to symmetrical intermixture between the latter *when in a gaseous state with but one of its atoms expanded* and oxygen ; thus



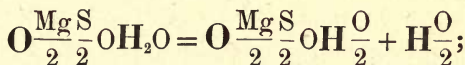
Next, as a typical case of a sulphate allying itself with different numbers of molecules of water under different conditions, we have the facts that magnesian sulphate, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (which according to the above arguments we suppose to be the result of seven successive symmetrical intermixtures with molecules of water), when it is heated

gives up five molecules of water with facility, the sixth less rapidly, the seventh not until a temperature of between 200 and 300° C. is reached.

The first of these analyses is probably represented by the equation



the second by the equation



the third and final analysis is probably due to the expansion of the manganese or sulphur atoms.

Finally, among the compounds of carbon and hydrogen, *the following complete series, such as we have supposed to be produced by successive acts of intermixture, is known to us* (all the terms of this series are gaseous under normal conditions).

Ethine or Acetylene, HC ,	$\left\{ \begin{array}{l} \text{The vapour density of} \\ \text{all these three compounds} \\ \text{indicates that one atom} \\ \text{only in a molecule is} \\ \text{greatly expanded.}^* \end{array} \right.$
Ethene or Ethylene, H_2C ,	
Ethane, H_3C	

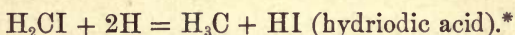
Methane (marsh gas), H_4C ; the vapour density of this compound indicates that two atoms in a molecule are greatly expanded.

The first term, *ethine*, is formed directly from its elements by causing the electric arc to pass between poles of dense carbon in an atmosphere of hydrogen.

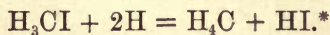
The second term, *ethene*, is produced by the combination of ethine with nascent hydrogen.

* It is owing to this that the three compounds are ordinarily written H_2C_2 , H_4C_2 , H_6C_2 respectively.

The third term, *ethane*, H_3C , is produced by the action of hydrogen upon an ethene haloid ether, H_2CI (ordinarily written $\text{H}_4\text{C}_2\text{I}_2$), a compound which, as we see, contains the preceding term H_2C . Thus—



The fourth and final term, *methane*, H_4C , is similarly obtainable from the preceding term combined with iodine. Thus—



We may remark that as we pursue our arguments further the conclusion will appear not unreasonable that *every individual* of the multitude of carbon compounds of organic chemistry—which is sometimes called *the chemistry of the carbon compounds*—owes its atom composition to successive symmetrical intermixtures, under particular conditions, and in certain proportions, of the four terms just referred to, HC , H_2C , H_3C , H_4C , with each other, and with other molecules or atoms.

The following interesting example of two different syntheses of the same compounds produced by two different sets of outward conditions is quite in harmony with the theory which has been offered that the nature of a chemical reaction depends on the nature of the gaseous states of the bodies taking part in it at the moment when it occurs.

When finely-divided oxide of manganese, MnO_2 , and sulphur dioxide, SO_2 , are brought together in water; if the liquid is kept cool we get manganous hyposulphate, MnS_2O_6 ; but if the temperature is allowed to rise, we get the sulphate MnSO_4 .

We may here offer a suggestion as to the production of *ozone*, a peculiar form of oxygen which has in the gaseous

* An explanation of the two metatheses, $\text{H}_2\text{CI} + 2\text{H} = \text{H}_3\text{C} + \text{HI}$ and $\text{H}_3\text{CI} + 2\text{H} = \text{H}_4\text{C} + \text{HI}$, is suggested in the sequel.

state just two-thirds the expansion of oxygen in its normal condition, and is strikingly different from the latter in its chemical behaviour.

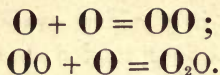
From its volume it is evident we should, according to the theory which has been offered above, suppose ozone to contain one condensed atom of oxygen to every two expanded atoms, so that its symbol should be written O_2O , or $O\frac{O}{2}$, according to whether we write it for each molecule to contain two similar expanded atoms, or only one. But the difficulty presents itself—how is the law of symmetrical intermixture, to whose agency we have just attributed the production of atom combinations of this nature, applicable to the formation of a body whose atoms are all of the same kind, since the action of this law depends on the atoms coming together having different readiness of compression.

The explanation suggested is that where ozone is formed secondary atoms of the same kind, being subjected to different electrical conditions, are experiencing different degrees of internal atom explosion, and are consequently in different electrical states, *i.e.*, have different proportions of the unimolecular ethers present among the primary atoms composing them ; and that, owing to this, we have atoms of the same kind manifesting different elasticity, or readiness of compression.

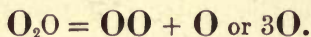
This view receives countenance from the fact that ozone is produced from normal oxygen *solely by the action of electricity* ; it is generally formed artificially by the influence of the silent discharge on pure, very dry oxygen whose temperature is being kept down by the presence of fragments of ice.

We suppose, then, that through some atoms of oxygen having different readiness of compression from others, the law of symmetrical intermixture operates just as though

atoms of different kinds were present, and that the formation of ozone is due to two acts of symmetrical intermixture.



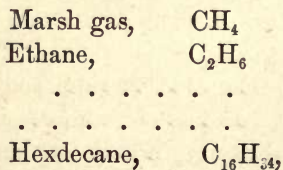
As we should expect, if ozone has one atom condensed, its conversion into oxygen may be effected by heat. Thus when ozonized oxygen is passed through a glass tube heated to 110° C. slight decomposition of the ozone takes place; at 200° the decomposition is very rapid, about 97 per cent. being converted into oxygen; and below 300° decomposition is complete.



The great oxidizing power of ozone may perhaps be due to the condensed state of some of its atoms causing the electrical effects to be more powerful when it is brought in contact with bodies which are emitting a different proportion of the unimolecular ethers; this suggestion will be understood better presently.

The supposition that the different atoms preserve their identity in compounds, each having its characteristic influence in determining the qualities of the compounds of which it forms part, seems supported by the fact that a gradation of physical properties is observed in what are known as homologous series of compounds.

Thus, taking the series of paraffins in which each term differs from the preceding in having an additional group, CH_2 , in its molecule.



we observe that the first four members of the series are gaseous at ordinary temperatures, and that the succeeding terms are liquids of increasing specific gravity as we pass along the series until in the final term we have a solid body ; and further that the boiling points of the series are in increasing order, the differences approximating to a regular law of gradation.

In closing this chapter we may state that the facts of crystallization will in the sequel be shown to furnish the completest evidence that the several atoms of crystallizing compounds occupy distinct portions of space, and that they are not linked together in groups to form concrete molecules, but that every atom is equally related to all the atoms similar to one another which touch it. These facts, and the conclusions as to the formation of molecules which we shall thus deduce from them, will therefore be found entirely in harmony with the theories just propounded.

CHAPTER XXXIV.

THEORY OF THE PRODUCING CAUSES OF CHEMICAL CHANGES
—APPLICATION OF THE THEORY TO SOME CASES OF
SYNTHESIS AND METATHESIS—QUANTIVALENCE.

IN the last chapter we endeavoured to show that the law of symmetrical intermixture is adequate to produce the various kinds of atom combination found in different chemical compounds *if we suppose that various appropriate changes of state of the molecular matter undergoing chemical change take place at different stages of this change.* Thus we suggested that methane, H_4C , may be the ultimate product of four successive acts of symmetrical intermixture, if HC , H_2C , H_3C , the supposed respective products of the first three acts, each, as it is formed, passes from the gaseous state of its formation in which two different atoms are expanded in each molecule, to the state of semi-expansion in which one atom only is expanded. We shall now endeavour to point out some probable causes of such changes of state as are thus supposed.

It has been suggested (p. 301) that both mere change of bulk and change of state of molecular bodies produced by heat are due to a lowering of the minima of the fluctuating values of the cohesion of some of the atoms composing these bodies, and that this is due to an increase in the quantity of the unimolecular ethers present within the interstices of the mass affected, which causes these ethers and the atoms at the molecular surfaces in contact with them to experience a fall of density.

In harmony with this we now make the general proposition that *all changes of state of molecular matter are due to alteration in the proportions or quantity or density of the unimolecular ethers present at the point where a change is experienced.*

And as to those cases where, on two different molecular masses being brought together, chemical change occurs *spontaneously*, without the aid of heat, or light, or chemical rays, or any other external agency, such as, according to the arguments of this treatise, would supply unimolecular ethers or produce ether liberation; it is suggested that when the contact between the two different kinds of matter takes place, changes in the ether conditions, productive of the requisite changes of state, are in most cases brought about by electrical action, the result of the different masses brought together emitting different proportions and quantities of the unimolecular ethers.* We suppose, in fact, that the excess of positive ether emanating from one kind of matter meets the excess of negative ether emanating from the other kind, and produces an accumulation of mixed unimolecular ethers, and a consequent rise of temperature (see p. 319).

There is, however, another way in which the contact of one kind of matter with another would appear to cause change of state, and which may account for some cases of spontaneous chemical change. The ether conditions prevalent about one kind of matter will, we argue, sometimes extend to particles of another kind of matter which are in close proximity, and modify the normal ether conditions of the latter. What we suppose to be examples of this effect of the presence of one kind of matter on another will be referred to immediately.

* We have based the explanations of several electrical phenomena on the conclusion that different substances emit different proportions of the two ethers (see pp. 74, 111, 130, and 141).

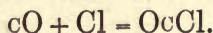
Like the cases of chemical change where a spark from without is the inciting cause, and the area of chemical action at once extends on every side from the mere point at which it originated, we conceive that chemical change occurring spontaneously is at first very local and very feeble, and that it is intensified and extended by means of the ether liberation and consequent heat it produces.

Supporting the theory to which we are led by the above, that changes of the ether conditions prevalent about molecular masses are instrumental in causing them to undergo chemical change, we have the well-known fact that the temporary application of heat, which, according to our previous conclusions, is a change of ether condition, commonly facilitates the production of fresh chemical compounds. And also pointing in the same direction, we have the fact that in many cases light, whose ether waves we have concluded produce atom explosion and ether liberation in bodies exposed to their influence, causes chemical change. Thus carbonic oxide, CO, unites with chlorine under the influence of sunlight to produce phosgene gas, COCl₂.*

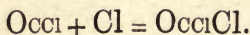
In support of the explanation above suggested of the spontaneous chemical changes sometimes occurring when different substances are brought into contact :—

* According to the arguments above offered, we suggest that the steps of the process are as follow :—

1. That in the presence of the chlorine the carbonic oxide has but half its normal volume, but one kind of atom being expanded, and that in this state it intermixes with chlorine, so that we have



2. That immediately on its production OcCl has its chlorine atoms condensed, taking the state of semi-expansion, OCCl, and that then a second intermixture with chlorine takes place :—



First, with reference to the suggested instrumentality of electrical action, we have the facts already referred to as to the spontaneous production of electricity on the contact of different substances, and we have also the important experimental fact, to which further reference will be made presently, that the intensest chemical action takes place between those bodies whose behaviour when exposed to an electric current would lead us to suppose that their ether emissions differ most widely—*i.e.*, between bodies one of which is highly electro-positive, the other highly electro-negative.

And besides this general evidence we have some interesting examples of change of state produced in some bodies by the presence of certain other bodies *in which the influence of one body on the other seems evidently electrical.*

Thus, if a piece of zinc be suspended in a solution of lead acetate, lead crystals are successively deposited in a continuous arborescent form, so that the process presents the appearance of growth; *and if, instead of placing the zinc in the acetate, we place in the latter a piece of platinum wire, and place the zinc in a separate vessel containing dilute hydrochloric acid, and then connect the zinc and the platinum, we have the same effect, so long as the latter continue in contact.**

We suppose the decomposition of the lead acetate to be an instance of electrolysis, *i.e.*, of chemical analysis by means of an electric current,† and that the lead separates from the solution in a liquid state, but passes immediately into the crystalline state owing to its experiencing new ether conditions; probably this latter change is due to a current of positive ether coming from the zinc.

There are other instances of chemical change in which,

* In the process of electro-plating and in the whitening of pins we have very similar effects.

† Of this kind of analysis an explanation will be offered presently.

as in the case just mentioned, the body which sets up a reaction undergoes no alteration, and which we suppose to be due to electrical action. Thus hydric peroxide, HO (generally written H_2O_2), is decomposed by the mere contact of many finely divided metals, and metallic oxides, without the latter undergoing any apparent change—*e.g.*, finely divided gold, silver, or platinum, procure an instant evolution of oxygen gas, and the finer the state of subdivision of the applied metal, the more rapid the decomposition.

Such reactions are accompanied by great heat, and it is suggested that the cause of the decomposition of the peroxide is the expansion by heat of all the atoms of some of its molecules, this enabling the hydrogen atoms of these fully expanded molecules to combine with others which are but partly expanded, so that water is formed, and oxygen set free. This is expressed by the equation—



The supposition that the change is due to heat is supported by the fact that hydric peroxide is an exceedingly unstable substance, and is readily decomposed by heat.

As to the origin of the heat, it is suggested that electric action takes place between the finely divided metal and the peroxide, and that this produces great molecule destruction locally, which causes the liberation of a considerable amount of unimolecular ethers, and, in consequence, the great rise of temperature observed.

It may, perhaps, be regarded as in favour of the view that the action of the metals is an electric action, that the presence of a few drops of an acid—*i.e.*, of a compound in whose composition *negative* atoms predominate—hinders the action of the electro-positive metal ; while the presence of an alkaline hydrate—*i.e.*, of a compound in whose composition *positive* atoms predominate—hastens the action.

In many cases where the decomposition of hydric peroxide is effected by metallic oxides, the oxides are themselves decomposed.

Finally, as cases in which the coming together of electro-positive and electro-negative atoms may be supposed to produce electrical action and consequent heat and molecule destruction, we may refer to the fact that when finely divided platinum, known as platinum black, or what is known as spongy platinum, comes in contact with a mixture of the gases oxygen and hydrogen, the metal, though cold, causes the mixed gases to explode, and unite, forming water; and to the analogous fact that crystals of iodine when applied to phosphorus which is exposed to the air cause its combustion.

Next, showing the probable efficiency of the second cause of change of state above suggested, we have direct evidence furnished by another class of cases that mere contact of one body with another, in some cases, produces a quiet gradual change of state. Thus we have the familiar fact of water absorbing atmospheric air and holding it condensed, and also the facts that platinum and kindred metals (especially when finely divided—*e.g.*, spongy platinum or platinum black) have the power of condensing oxygen and other gases upon their surfaces; finely divided platinum at ordinary temperatures absorbing about 240 times its volume of hydrogen; and finely divided palladium, at 200° , nearly 700 times its volume of hydrogen.

The condensation of atmospheric air by water—*i.e.*, in the language of our theories of change of state, the passage of the minima values of the fluctuating density and cohesion of those atoms in the oxygen, nitrogen, and other gases composing the atmosphere whose expansion produces the gaseous condition, past the respective critical values at which, in these different gases, the cohesion

becomes high enough to prevent the existence of expansive force in such atoms—we are disposed to attribute to an increase of intermolecular pressure caused by the presence of the water, and due to a greater amount of explosion of primary atoms, and consequent ether liberation, proceeding among the molecules of water than among the molecules of the gases composing the atmosphere.*

The condensation of gases by platinum, and other kindred metals, we are disposed to attribute to great density of the unimolecular ethers of these bodies, which we suppose subsists,† the dense unimolecular matter raising the minima values of the fluctuating local density and cohesion within any particles of gas coming into very close proximity to the metals emitting it.

A reference to one or two familiar examples of synthesis, and of metathesis, to which the above theory of the origin of spontaneous combination will apply, may in this place be instructive.

The two gases ammonia, H_3N , and hydrochloric acid, HCl , when they meet in the same receptacle combine and produce a crystalline solid, ammoniac chloride, H_4NCl .

Our theory of this change is that as a first step the fully expanded gases, HNH_2 , HCl , through contact with one another, both experience a change of state to a condition of half-expansion ; HNH_2 perhaps passes to the condition NH_3 , and HCl to the condition HCl ; that next the two denser gases thus produced, being each capable of intermixture through having but one kind of atom expanded, symmetrically intermix.

* As already stated (pp. 35 and 326), we suppose that pressure adequate to convert bodies from the gaseous to the liquid or solid states is furnished by the expansion of ether liberated by molecule destruction.

† Their high specific gravities are in harmony with this supposition (see p. 49).

Thus $\text{NH}_3 + \text{HCl}$ would produce NH_4Cl .

And that finally the change in the ether conditions produced during the act of intermixture causes a further change of state, so that the ammoniac chloride directly it is found in the gaseous state, passes to the liquid state, and thence to the state of crystallization.

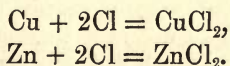
As a second example we have the combination of nitric oxide with oxygen, which has been already referred to (p. 362).

In this synthesis the occurrence of molecule destruction to which, probably, we may refer the condensation which brings about change of state, seems indicated by the heat produced, of which the momentary expansion when the gases first meet is evidence. It may further be noticed that if our conclusions as to the origin of colour are accepted (see p. 258), we have evidence, in the deep red tint of the nitric peroxide vapour, of the continuance of considerable atom explosion in this compound after its formation.

As a third example :—

Brass tinsel, that is to say tinsel composed of an alloy of copper and zinc, being exposed to chlorine gas, chemical union at once takes place, the product being a mechanical mixture of cupric chloride and zincic chloride ; so much heat is produced that the tinsel becomes incandescent.

The two similar reactions which occur are expressed in symbols thus :—



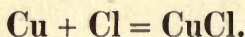
Taking the first of these, the explanation suggested is :

That since of the three bodies coming together, copper, zinc, and chlorine, the zinc is highly positive and the

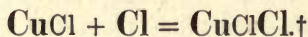
chlorine highly negative,* minute electric currents are produced when the contact takes place which cause accumulations of the unimolecular ethers and consequent heat (see p. 319).

That these ether accumulations cause molecule destruction which, at first insignificant, becomes more and more violent as ethers liberated by it accumulate, this being evidenced by the incandescence of the metals (see p. 260). Perhaps the molecule destruction is facilitated by the difference in readiness of compression of the different kinds of atoms causing them to vibrate out of harmony.

That the heat produced by the presence of the unimolecular ethers which thus accumulate expands the atoms of copper, upon which these atoms symmetrically intermix with the expanded chlorine atoms, and we have



That as the temperature begins to fall the fully expanded atoms, CuCl , thus formed, pass to a state of semi-expansion, and then take part in a second symmetrical intermixture with chlorine atoms, so that we have



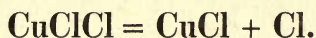
And as a final step ; that, as the temperature falls still

* See Berzelius's series (p. 393).

† It may be that the chlorine not the copper atoms are expanded in the molecules of CuCl , but as in this case the atoms intermixing would be of the same kind, we should then have to suppose that different ether conditions were prevalent among the atoms of chlorine in the molecules, CuCl , from those prevailing among the atoms of chlorine in the chlorine gas, productive of different readiness of compression in the two sets of atoms, for without the latter condition the law of symmetrical intermixture would not be in force. That atoms of the same kind are sometimes symmetrically intermixed we have already concluded from the case of ozone (see p. 367).

further, the gaseous cupric chloride thus formed passes through the liquid to the crystalline state.

Supporting the above suggested explanation we have the fact that if cupric chloride, CuCl_2 , is heated it fuses, and at a red heat gives up half its chlorine, so that cuprous chloride, CuCl (commonly written Cu_2Cl_2), remains. For evidently we may regard this as the converse of the above, and, in accordance with the theory of analysis above suggested, suppose that the breaking up of the cupric chloride by heat is due to all three atoms in each molecule, CuCl_2 , expanding when a sufficient rise of temperature has taken place; the law of symmetrical intermixture thereupon separating the unsymmetrical mass into masses of symmetrical cuprous chloride gas and chlorine (see p. 355). Thus :—



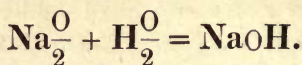
The explanation of the similar reaction between the zinc and the chlorine will be very similar.

As a fourth example we may take the combination of a solid with a liquid :—Sodium monoxide, Na_2O , combines with water, H_2O , producing sodium hydroxide, NaOH .

In this, as in the last example, we may suppose that, when the different atoms come together, electric action, molecule destruction, and heat are produced, so that both bodies are vaporized, and that the result is that in the sodium monoxide molecules the two atoms of sodium, and in the water molecules the two atoms of hydrogen, are expanded.

As both kinds of molecules will, if this be the case, have but one kind of atom expanded, we may conclude that symmetrical intermixture will thereupon take place between them.

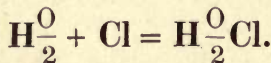
Thus, if we write each kind of molecule to contain but one expanded atom, we have



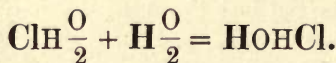
As before, we suppose the final step, which immediately follows, to be the passage of the symmetrical gas thus formed, through the liquid, to the crystalline state.

As a fifth example :—If a current of chlorine be passed through a mixture of crushed ice and water, the definite hydrate $\text{Cl}_2, 10\text{H}_2\text{O}$ is obtained in a crystalline state.

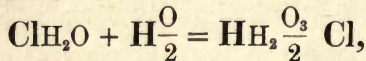
Here the first step would, according to our theories, be the symmetrical intermixture of aqueous vapour having two atoms of hydrogen expanded in each molecule, with chlorine. Thus, writing the molecule of water to contain but one expanded atom,



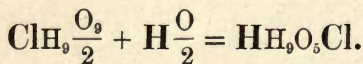
We suppose the intermediate compound thus produced, immediately on its production to change its state to a condition of half-expansion, $\text{ClH}\frac{\text{O}}{2}$, and then to intermix with a further molecule of water. Thus :—



As before, we suppose a change of state thereupon occurs, making a third intermixture with gaseous water molecules possible.



and so on till we reach the intermixture,

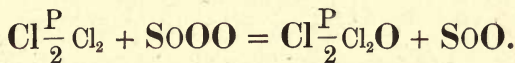


Finally we suppose that the last-named compound, which may be written, $\text{Cl}_2, 10\text{H}_2\text{O}$, when formed instantly passes to the liquid, and thence to the solid state without affording opportunity for further symmetrical intermixture.

Of reactions in which one compound appropriates a portion of another, we may take one of those cases in which sulphur trioxide, SO_3 , readily parts with one of its atoms of oxygen to another compound.

If sulphur trioxide and phosphorus trichloride are mixed together at a normal temperature the trioxide loses one of its atoms of oxygen, which is added to the trichloride forming phosphorus oxychloride, $\frac{\text{P}}{2}\text{OCl}_3$.*

Probably the nature of this reaction is expressed thus :



A strong red heat is ordinarily necessary in order to resolve sulphur trioxide into the dioxide and oxygen, and the conclusion to which we are led is that, in the above case, such a heat is produced by the electrical action, and the consequent atom destruction, taking place when the two compounds are brought together.

Next as an example of metathesis :—

If a piece of sodium be brought in contact with water, upon which it floats, the sodium fuses, vigorous chemical action ensues, hydrogen is evolved, and solid sodium hydroxide (caustic soda), NaOH , is formed.

Here we have the highly positive element sodium coming in contact with the less positive water molecules, and, as in the case of the above combination of sodium monoxide and water to produce sodium hydroxide, we suppose that electrical action is set up which produces rise of temperature and initiates molecule destruction.

* As to the atomic weight of phosphorus, see Note §, p. 345.

Upon this we suppose that the heated sodium partially vaporizes so that we have sodium vapour in contact with water vapour, and that, in accordance with the above theory of metathesis (see p. 358), the expanded atoms of hydrogen and oxygen and the expanded atoms of sodium all become mixed together where the boundaries of the vapours of water and sodium meet.

And we suppose, finally, that a greater difference in readiness of compression subsisting between the expanded oxygen atoms and the expanded sodium atoms than between the former and the expanded hydrogen atoms, symmetrical intermixtures of sodium and expanded hydrogen dioxide OH are formed and the expanded hydrogen atoms isolated.

This process would be expressed as follows :—



If instead of sodium we use the metal potassium a precisely corresponding reaction takes place, but in this case the heat produced is adequate to inflame the displaced hydrogen,* which combines with the oxygen of the atmosphere to form water.

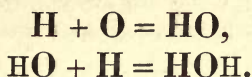
To explain this in terms of our theories :—We suppose that when potassium is employed, the quantity of intermixed ethers accumulated is sufficient to produce a high initial expansion of the liberated hydrogen and of the oxygen of the atmosphere present at the place of the reaction, and also much molecule destruction and consequent ether liberation ; that as the hydrogen is liberated, it therefore expands to a highly tenuous state, and while in this state symmetrically intermixes with oxygen similarly expanded.† Finally that, certain of the atoms becoming

* Combustion is referred to subsequently.

† See Note *, p. 348.

condensed by pressure arising from the ether liberation, the further intermixture necessary for the production of water follows.

The two intermixtures supposed to occur are,



Another simple metathesis, of which a similar explanation is offered, occurs when sodic hydrate, the product of the metathesis just dealt with, comes in contact with a solution of hydrochloric acid,* a mixture of common salt and water being then produced.

We suppose that the hydrochloric acid, half of whose atoms consist of the highly negative element chlorine, emits more negative ether than the sodic hydrate does, that therefore when the bodies come together, we have, as before, electrical action, heat, and molecule destruction, resulting in the expansion of several kinds of atoms to the gaseous state; and that the rearrangement which follows is, as suggested in other cases, due to the different readiness of compression of different atoms.

The supposed steps of the process would be written,—



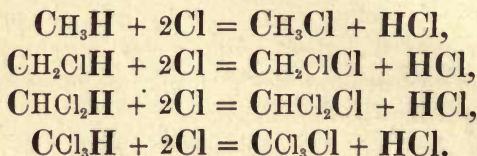
the molecules OH, which when met with alone are known as hydric peroxide, passing unbroken through this as through the former metathesis.

We may mention next a group of metatheses which are instructive as furnishing a probable example of successive steps of metathesis analogous to the successive steps of synthesis by which we have supposed complex compounds are built up.

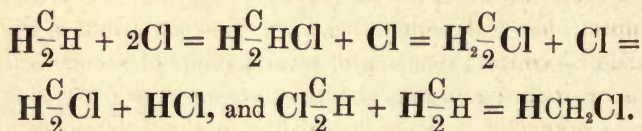
* Some special reference is made to acids in a subsequent chapter.

When chlorine and methane, CH_4 , are mixed and exposed to diffused light (explosion takes place in direct sunlight), the whole series of derivatives, monochloromethane, CH_3Cl ; dichloromethane, CH_2Cl_2 ; trichloromethane, CHCl_3 ; and tetrachloromethane, CCl_4 , are formed, the displaced hydrogen combining with chlorine and producing hydrogen chloride, HCl .

Perhaps the following are the successive metatheses :—



But possibly some of the compounds may arise differently, thus :—

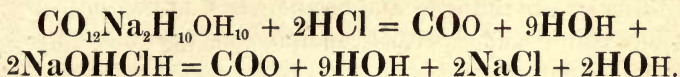


We may mention, finally, a metathesis which goes to show that atoms sometimes preserve their characteristic individual properties when they are combined with other atoms;—i.e., that we may have the effect of particular groups of atoms on other particular groups *not altered by the presence of other atoms in combination with one kind of these groups*.

If a solution of hydrochloric acid be poured upon sodic carbonate (common soda), a violent effervescence takes place, carbonic dioxide, CO_2 , is liberated, and the other products of the reaction are found to be common salt and water.

Except that other atoms are present, which, when the expansion to gas occurs, segregate by themselves, it seems

evident that this metathesis may be regarded as of the same nature as the reaction between sodic hydrate and hydrochloric acid above referred to, the process being expressed by the equations—



To render our theory of chemical combination complete we suppose :

*That for gaseous mixtures to have the stability without which intermixture will not result in chemical union, but will continue mere intermixture, they must have a greater expansion at the moment the intermixture takes place than subsequently.**

For, if this is the case, a minimum mass † of the compound after intermixture has taken place will exceed in magnitude one of the combining molecules, consisting of an expanded secondary atom and its proportion of condensed atoms, if such are present, and, consequently, the internal motions occurring in every mass, which tend to separate particle from particle, will not be able to separate any portion of it into distinct atoms, or molecules.

In support of this supposition we have the well-known fact that heat, an agent which produces expansion, is always found where there is chemical change, and further, which is still more direct evidence, we have the fact that in many cases very great expansion is found to occur at the moment when a chemical change takes place—notably in the case of explosions.‡

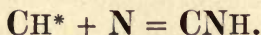
* This has been already suggested of compound gases of two atom molecules whose volume is the sum of the gaseous volumes of their components (see Note *, p. 348).

† See p. 9.

‡ We shall, however, conclude subsequently that explosions are not entirely due to sudden gaseous expansion.

In harmony with this, we suppose that the passage of the electric discharge produces chemical combination in so many cases owing to its power of producing great atom expansion.

Thus, when nitrogen and ethine gases mix at ordinary temperatures under normal conditions we have mere intermixture, but when electric sparks are passed through the mixture hydrocyanic acid is formed—



Consistently with the above, we suppose that when compounds decompose directly they are expanded to the gaseous state, it is because the conditions are such that they reach, and continue at a degree of expansion as great as that at which their formation took place.

One word in closing this chapter on the subject of *quantivalence*, as it is called.

When two different kinds of secondary atoms, or secondary molecules are brought together, and chemically combine, they, in the greater number of instances, do not form a *stable compound* of an *equal* number of each kind, but of different definite simple proportions of the two kinds. Taking the combination of atoms, for instance, we have as stable compounds H_2O , H_3N , H_4C , CrF_6 .

Further, when we compare many different combinations, we find a striking approximation to the general law, that comparing the quantities of different elements combining with the same element or compound to produce stable compounds, the atoms of the various elements have certain different proportionate values for combining purposes—the relative valency of hydrogen, oxygen, nitrogen and carbon being, for instance, expressed by the figures 1, 2, 3 and 4 respectively.

* Ethine is generally written C_2H_2 , on account of its having the volume expressed by CH .

Thus when one atom of carbon will effect a stable combination with some given atom or group of atoms, it is generally found that, if hydrogen will combine with the same atom or group of atoms, four atoms of hydrogen are requisite to form the corresponding stable compound.

The law just referred to, which however is only a very partial one, is called *the law of quantivalence*, and its existence has led to an endeavour to frame a table of relative quantivalence, in which the various elements are called monads, dyads, triads, etc., as one of their atoms is equivalent for combining purposes to one, two, three, etc., atoms of hydrogen.

We here subjoin a table of quantivalence taken from the "Encyclopædia Britannica," Art. "Chemistry," p. 473, in which a number of the elements are arranged mostly according to their apparent maximum valency.

<i>Monads.</i>	<i>Dyads.</i>	<i>Triads.</i>	<i>Tetrads.</i>	<i>Pentads.</i>	<i>Hexads.</i>
Hydrogen Fluorine Chlorine Bromine Iodine Potassium Sodium Lithium Silver	Oxygen Barium Strontium Calcium* Magnesium Zinc Cadmium Copper Mercury*	Boron Gold	Carbon Silicon Tin Lead Aluminium Indium Thallium Iron Chromium Manganese Cobalt Nickel Platinum Palladium	Nitrogen Phosphorus* Arsenic* Antimony Bismuth	Sulphur Selenium Tellurium Tungsten Molybdenum

Now as to the direction in which we must look for an explanation of the facts of quantivalence:—We have concluded that the relative numbers of the different kinds of atoms which will combine in any given instance of chemical action will depend on how many successive symmetrical

* This table is not corrected to show the true position of those elements which are believed to have different atomic weights from those usually received (see p. 345).

intermixtures take place ; and we have also concluded that further symmetrical intermixture is possible in any given case only when the product of the last previous intermixture passes into a state in which but one kind of atom is expanded.

Again, we have argued that the state of a mass ;—*i.e.*, whether it shall be gaseous, liquid, or solid, and, if gaseous, how many atoms it shall have expanded ;—depends not only on the outward conditions prevalent, *but also on the nature of the ether emissions of the atoms themselves.*

Therefore the valency of any particular element, or compound may be expected to depend chiefly on the nature of its ether emissions, to be, in fact, an index of the potency of these ether emissions to cause change of state of masses of atoms of which the element or compound forms part.

Probably this is sufficient to account for the degree of regularity of behaviour of the different elements revealed by the facts of quantivalence.*

And it is an explanation which seems to be countenanced by the fact that commonly the quantivalence of a radicle, or compound is found by deducting the quantivalence of the negative atoms from that of the positive, or *vice versâ*.

Deferring for the moment the consideration of the distinguishing features of acids, alkalies, and salts we shall in the next chapter devote a few pages to the subject of electrolysis.

* Variations of external conditions commonly produce more or less variation of valency, especially in the case of organic compounds.

CHAPTER XXXV.

ELECTROLYSIS.

WE have supposed (p. 359), that there is a possibility that in some cases chemical analysis is caused by atoms being shaken out of a mass while they are in a condensed state, instead of by their being separated through the action of the law of symmetrical intermixture exerted on them and on other atoms with them while in a state of gaseous expansion. We shall now offer an explanation of the kind of analysis known as *electrolysis*, based on some such conception, this kind of analysis, according to the theory we shall offer, not being preceded by momentary expansion of some of the atoms concerned to the state of gas, as we have supposed to be the case in other instances of analysis.

The most familiar example of electrolysis—the decomposition of water by the electric current—is exhibited as follows :—

A cell is filled with water, slightly acidulated with sulphuric acid to improve its conducting power ; two strips of platinum immersed in the water and in proximity to each other are respectively connected with the two terminals of a voltaic battery, so that the positive electricity disengaged at one pole passes from one of the strips of platinum to meet the negative electricity disengaged at the other which passes from the other strip. The effect on the liquid is that bubbles of gas are found to be collecting upon each of the strips, and when means are taken to collect

these bubbles, it is found that those from the positive pole consist of oxygen, those from the negative pole of hydrogen, and that the quantities of the two gases liberated bear the same proportion as that in which these two elements combine to form water.

The theory of electrolysis suggested here is as follows:—

In consequence of the different readiness of compression of the different kinds of secondary atoms composing a chemical compound, these atoms, it is submitted, when the compound is in the liquid state, tend from time to time to take up as symmetrical a relative arrangement in space as possible,* but as the conditions can never be such that absolute symmetry is attainable, and as moreover these conditions are varied locally to a slight extent by every passing wave-disturbance, the process never results in complete equilibrium, and the atoms continually perform inconsiderable motions with respect to one another.†

Now, from our arguments respecting electric conduction, we conclude that the moving unimolecular ethers, whose passage in opposite directions constitutes an electric current, have different degrees of cohesion to different secondary atoms among which they are flowing, *according to the kind of ether which the various atoms are emitting through the destruction of some of their primary atoms*—that the moving positive ether lays a firmer hold of the secondary atoms from which most positive ether is being emitted, the

* The nature of the different symmetrical arrangements towards which different classes of compounds tend—*e.g.*, the nature of the symmetrical arrangement of the atoms of oxygen and hydrogen in water—will be considered in a subsequent chapter on crystallization.

† We do not suppose that the continual shifting of the relative position of the different secondary atoms caused in this way is sufficient to produce any appreciable rupture of their continuity, but that one atom slides on another.

moving negative ether a firmer hold of those from which most negative ether is being emitted.*

Therefore, in any slight rearrangement of atoms from time to time occurring, as just explained, some atoms have a greater disposition to move their position towards one pole than in any other direction, and others a greater disposition to move theirs towards the opposite pole than in any other direction; and as a consequence of this we have some atoms shaken, as it were, out of the intermixture towards one pole, and other different atoms shaken out towards the opposite pole, the bulk of the atoms in the meantime continuing to occupy a practically identical symmetrical disposition of their different kinds.

And finally, as a consequence of the intermixed atoms thus preserving the same symmetrical arrangement, and therefore practically the same proportions of the different kinds, the number of atoms shaken out of intermixture at one pole is complementary of the number of different atoms shaken out at the other pole; *i.e.*, the proportions of the different atoms liberated are those subsisting in the compound electrolysed.

The following facts with regard to electrolysis support the theory which has just been stated.

(1.) Bodies capable of electrolytic decomposition are fluids.

(2.) No alteration takes place in any part of the fluid electrolysed except at the two terminals or poles of the battery.

(3.) The quantity, that is the mass, of the electrolyte decomposed is proportional to the quantity of electricity which passes through it. In other words, it is jointly proportional to the strength of the current and the time that it lasts.

* That positive ether holds most continuously to positive, negative ether to negative, see p. 66.

(4.) The two primary products of decomposition do not appear together, but one appears at the positive the other at the negative pole, and they appear in the same proportions as those in which they subsist in the undecomposed electrolyte.

(5.) The quantities of different electrolytes decomposed by the same quantity of electricity are in the ratio of their chemical equivalents (see p. 386), or, to state the case in the language of the theory above submitted, if two different electrolytes have their constituents successively subjected to the action of the opposite drawings of the same quantity of moving ethers—i.e., the same electrical current—it is found that the respective quantities of the electrolytes thus drawn out of the molecular combination are in such proportions as would take part in “double decomposition” between themselves.*

The following definitions were invented by Faraday, who first established the laws just referred to.

(1.) As already stated, the substance decomposed is called an *electrolyte*, and the process of decomposition is called *electrolysis*.

(2.) The two portions into which the electrolyte are primarily divided, no matter how complex, are called *ions*; that disengaged at the positive pole is called the *anion*, that disengaged at the negative the *cation*. Thus, in the instance of decomposition of water, the oxygen is the anion, the hydrogen the cation.

(3.) The poles in the *electrolyte* are called *electrodes*, that at which the anion is disengaged is called the *anode*, that at which the cation is disengaged the *cathode*.

It is evident that the course taken by different elements

* Prof. F. Kohlrausch of Würzburg has shown that in diluted solutions of salts, including hydrates of acids and hydrates of caustic alkalies, every atom under the influence of currents of the same density moves on with its own peculiar velocity.

with respect to each other, when they are set free from a compound submitted to electrolysis, may be expected to furnish some information as to the relative ether constitution of such elements. Suppose, for example, that, as in the case of water, there are but two elements, one passing towards the negative, the other towards the positive pole, it may reasonably be concluded, if our foregoing theory of the process be a correct one, that the element which passes towards the positive pole (the oxygen in the case of water) has more negative ether among its primary atoms than has the element which passes towards the negative pole (the hydrogen in the case supposed).

The view once held by Faraday, that a given element is unalterably either an anion or a cation, has been disproved by the fact that the same element may act as an anion in one solution and as a cation in another ; but an attempt has been made to arrange the elements in a series such that in a compound of an element A with any one of those above it, A would appear as a cation, but in a compound with any of those below as an anion. Of any two elements the one which stands first in such a series (being that more ready to pass towards the positive pole, *i.e.*, according to our theory, to travel with the negative ether of the current) is called more *electro-negative*, and the other element (which passes more readily towards the negative pole, *i.e.*, with the positive ether of the current) is called more *electro-positive*.

The electro-chemical series as determined by Berzelius is as follows.*

Electro-negative.

Oxygen	Bromine	Molybdenum
Sulphur	Iodine	Tungsten
Selenium	Phosphorus	Boron
Nitrogen	Arsenic	Carbon
Fluorine	Chromium	Antimony
Chlorine	Vanadium	Tellurium

* Taken from "Enc. Brit.," Art. "Electrolysis," p. 112.

Tantalum	Bismuth	Aluminium
Titanium	Tin	Didymium
Silicon	Lead	Lanthanum
Hydrogen	Cadmium	Yttrium
Gold	Cobalt	Glucinum
Osmium	Nickel	Magnesium
Indium	Iron	Calcium
Platinum	Zinc	Strontium
Rhodium	Manganese	Barium
Palladium	Uranium	Lithium
Mercury	Cerium	Sodium
Silver	Thorium	Potassium
Copper	Zirconium	Electro-positive.

We may urge upon the reader that the behaviour of the different elements which allows of the formation of such a series furnishes strong testimony in favour of the views which have been submitted as to the ether structure of the elements.

Before concluding these few remarks on electrolysis, we may just mention one or two additional facts.

The separation of several metals from their oxides was first accomplished by means of electrolysis, the metal, in the case of decomposition of such binary compounds, always passing to the negative pole.

When more complex substances are decomposed by electrolysis, the primary separation into two constituents is often followed by secondary actions. For instance, sodium sulphate is presumably first divided so that sodium (Na_2) passes to the negative pole, and sulphur and oxygen (SO_4) to the positive. But the liberated sodium at once unites with the oxygen of the water, and so liberates hydrogen, and the sulphur and oxygen produce sulphuric acid at the negative pole, liberating oxygen.

And as another instance. When potassic carbonate (K_2CO_3) gives up potassium at the negative pole, and the atomic aggregate, CO_3 , at the positive, the potassium instantly combines with the molecules of water, and the

aggregation, CO_3 , is resolved into a mixture of carbonic dioxide, CO_2 , and oxygen.

The conditions requisite in an electrolyte to insure conduction are, according to our arguments, molecular, and it would appear that some degree of irregularity in the disposition of the molecules favours conduction. Thus, two non-conductors, as water, HOH , and hydrochloric acid, HCl , on being mixed, form a very good conductor.

The peculiar molecular state of some of the elements liberated by electrolysis may be referred to. Thus oxygen partly takes the shape of ozone. The molecular state of the deposit of metals effected by electrolysis varies very much with the density of the current. Thus, when the density of the current is small, metals are deposited in crystals; when it is increased they take a form similar to that of melted metal; and when the density is great the deposit is amorphous, botryoidal, or pulverulent.

The metal separated from an electrolyte commonly *alloys* with the metal of the electrode to which it passes. Thus copper deposited upon platinum alloys with it to a certain extent, the alloy penetrating to a considerable depth; and the same occurs in the case of the electrolysis of many metals and salts with mercury electrodes.

Still more noteworthy is the combination of liberated gases with an electrode, *e.g.*, oxygen or hydrogen become condensed (liquefied) and pass into the substance of a platinum electrode. Root has found that in some cases the gases thus alloying an electrode of platinum penetrate it and appear at the opposite side to that at which they enter.

Some interesting observations have been made on the motion of solid particles and other bodies in fluids of high resistance; perhaps a careful examination of the motions of such bodies would throw light upon the relative distribution of the two opposite currents of the two ethers whose motions constitute an electric current.

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